72

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course for Meteorological Assistants

Issued for the information and guidance of all concerned.

By command of the Air Board.

Secretary.

Air Force Headquarters,
Melbourne, C.1

By Authority: Victorian Railways Printing Works, North Melbourne.
241—42

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course for Meteorological Assistants

Issued for the information and guidance
of all concerned.

By command of the Air Board.

Secretary.

Air Force Headquarters.
Melbourne, S.C. 1

By Authority : Victorian Railways Printing Works, North Melbourne.
3241—42

R.A.A.F. Publication No. 248
(July, 1942).

The amendments promulgated in the undermentioned amendment lists have been made in this publication :—

Amendment List.		Amendment made by—	Date.
No.	Date.		

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course
for

Meteorological Assistants

PART 1

Observational Meteorology

Introduction

This publication is designed primarily for the use of Meteorological Assistants. It covers also the preliminary course in the training of forecasting Officers, who undertake, in addition, a course on forecasting and more advanced aspects of Physical Meteorology. Synoptic Meteorology has not been included, as much of this subject is, during war, of a confidential nature and varies from time to time according to the purposes for which codes are required.

The subject matter is divided into four parts as follows :—

PART I. OBSERVATIONAL METEOROLOGY—

This deals with the observations to be made, methods of making the observations and calculations from observed data.

PART II. INSTRUMENTAL METEOROLOGY—

This section deals with the various types of instruments used in Meteorology, describes them together with their uses, and gives methods of testing their efficiency and of making adjustments.

PART III. ELEMENTARY PHYSICAL METEOROLOGY—

This section delineates the physical processes underlying aspects of Meteorology.

PART IV. AERONAUTICAL METEOROLOGY—

The data included in this section is intended to be supplementary to the information given in " R.A.A.F. Manual of Meteorology No. 153 ", which was compiled largely with requirements of Pilots and Navigators in mind.

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course
for

Meteorological Assistants

PART 1

Observational Meteorology

OBSERVATIONAL METEOROLOGY

CONTENTS

*See References.

SECTION 1

OBSERVATIONAL METEOROLOGY

THE NATURE AND TIME OF METEOROLOGICAL OBSERVATIONS

The subject of Observational Meteorology deals with the theoretical and practical aspects of all observations made for meteorological purposes.

Meteorological observations may be classified as "instrumental" or "non-instrumental." In some cases the instrumental observations provide the required information by direct reading; in others calculation or the application of physical tables is necessary before the desired data concerning atmospheric conditions are available. Non-instrumental observations include those of a descriptive and of an estimated nature.

The instrumental observations include those made—

(a) With direct reading instruments:—

Barometer ..	For determining atmospheric pressure.
Thermometer.	For dry bulb, wet bulb, maximum, minimum, solar and terrestrial radiation temperatures.
Anemometer.	For wind direction, velocity and fluctuations.
Pilot Balloon.	
Theodolite ..	For the direction and velocity of upper winds.
Cloud searchlight	For the height of the base of the cloud.
Nethoscope ..	For the direction and velocity of cloud movement.
Rain gauge .	For the amount of precipitation.
Sunshine Recorder .	For the number of hours of sunshine.
Evaporimeter.	For the amount of evaporation.

(b) With autographic self-recording instruments:—

Barograph ...	Showing the atmospheric pressure and its fluctuations.

Thermograph.	Recording temperature and its changes and indicating the times of occurrence of the maximum and minimum readings and of cool changes.
Hygrograph .	Recording relative humidity.[1]
Anemograph.	Recording wind direction and velocity with magnitude of its fluctuations and the times at which they occur.
Pluviograph. .	Recording rainfall.

The data which can be derived from these observations after calculation include determinations of relative humidity, vapour pressure, dew point, water content, atmospheric pressure at station level and mean sea level under standard conditions, cloud velocities and directions of wind in the upper atmosphere.

The non-instrumental observations include estimations of cloud height, type, movement and amount, visibility, wind velocity and direction and descriptions of the state of the sky, past and present weather, the state of the ground, optical and special phenomena, etc. In some cases the estimations are replaced by instrumental measurement of cloud height and movement, and wind direction, velocity and fluctuations.

Full meteorological data provide information which can be applied to various functions.

(a) Climatological—involving the determination of the climate of stations and regions.

(b) Forecasting—inferring future weather conditions along air routes and over regions for periods up to 24 hours or more ahead.

(c) Aviation advices—providing aircraft and operating aviation organizations with information as to flying conditions in various regions and along various air routes.

(d) Special purposes—supplying to various Arms of the Defence Services, agriculturalists, etc., information regarding special aspects of weather conditions.

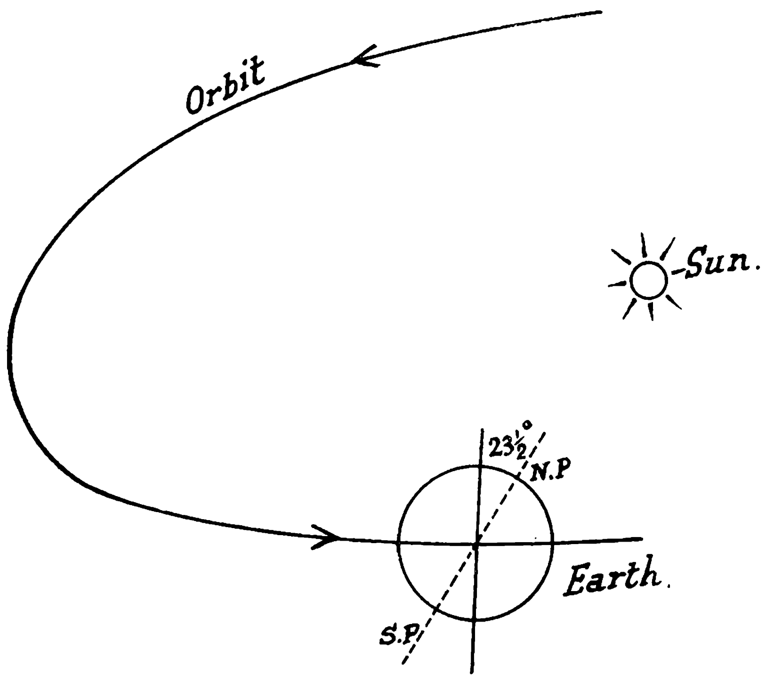
(e) Items of research.

Unless they are required for a special purpose, observations are made so that they are completed at fixed times. The fixed times are determined in relation to the purpose for which the information is obtained and the elimination of the effects of "diurnal" variations of the elements. For example, observations required for forecasting purposes should be made simultaneously, but those for climatological purposes should be made at the same "local" time, so that the "diurnal" effects will not upset the comparative relationship between observations made at various stations.

The time at which observations for climatological purposes are made are 0900 and 1500 hours, "local" mean time. The stations on the "forecasting" network make observations at 0300, 0600, 0900, 1200, 1500, 1800, 2100 hours, Eastern Standard Time.

TIME

In 1610 A.D., Gallileo conclusively established the theory of Copernicus that the earth, rotating from west to east about its own axis, once in 24 hours, completes an orbit, or path, around the sun in approximately 365¼ days. This may be shown diagramatically as under—



The earth rotates at the rate of 360° in 24 hours, or 15° per hour; and moves along its orbit at the rate of 360° in 365¼ days, or approximately 1° per day.

The orbit is slightly elliptical, and the sun is at one focus. The earth travels along its orbit with its axis inclined at approximately 66½° to the plane of the orbit, so that the plane of the equator makes an angle of 23½° with the plane of the orbit.

The daily movement of the earth about its axis is perfectly uniform, but the earth varies its angular speed in its elliptical orbit.

The "Apparent Solar Day" is the interval of time between two successive transits of the sun across the observer's meridian. This is divided into 24 hours of Apparent Time of the True Sun. Apparent time is directly indicated by a sundial or sunshine recorder.

The "Mean Solar Day" is the average length of all the apparent solar days, throughout a number of years. This is divided into 24 hours of 60 minutes each of 60 standard seconds. Thus, the Mean Solar Day is the time indicated by 24 hours on a clock set to civil time.

The difference between "apparent time" (as indicated by the position of the true sun) and "mean time" (as indicated by the position of the "mean" sun) is called the "equation of time" (E.T.) and may be as much as 16 minutes.

The equation of time is such that—

Apparent Time + Equation of Time = Mean Time.

or A.T. + E.T. = M.T.

When referring to the time at the place of observation the term local (L) is prefixed to the time, so that we have—

L.A.T. + E.T. = L.M.T.

and L.M.T. — E.T. = L.A.T. . . . (A').

L.A.T. — L.M.T., or E.T. at Greenwich (Longitude 0°) is tabulated in the Nautical Almanac.

EQUATION OF TIME

(To be added to Apparent Time to find Mean Time)

Day		Jan.	Feb.	Mar.	Apr.	May	June
1	..	+3	+13½	+12½	+4	−3	−2½
4	..	+4½	+14	+12	+3	−3½	−2
7	..	+6	+14	+11	+2	−3½	−1½
10	..	+7½	+14½	+10½	+1½	−3½	−1
13	..	+8½	+14½	+9½	+½	−4	0
16	..	+9½	+14½	+9	0	−4	+½
19	..	+10½	+14	+8	−1	−3½	+1
22	..	+11½	+14	+7	−1½	−3½	+1½
25	..	+12	+13½	+6	−2	−3½	+2½
28	..	+13	+13	+5	−2½	−3	+3
31	..	+13½	—	+4½	—	−2½	—
Day		July	Aug.	Sept.	Oct.	Nov.	Dec.
1	..	+3½	+6	0	−10½	−16½	−11
4	..	+4	+6	−1	−11	−16½	−9½
7	..	+4½	+5½	−2	−12	−16	−8½
10	..	+5	+5	−3	−13	−16	−7
13	..	+5½	+4½	−4	−13½	−15½	−6
16	..	+6	+4	−5	−14½	−15	−4½
19	..	+6	+3½	−6	−15	−14½	−3
22	..	+6	+3	−7½	−15½	−14	−1½
25	..	+6½	+2	−8½	−16	−13	0
28	..	+6½	+1	−9½	−16	−12	+1½
31	..	+6	+½	—	−16½	—	+3

1 Civil Year = 365·2425 Mean Solar Days (average over 400 years).

1 Mean Solar Day = 24 hours.

1 Apparent Solar Day = 24 hours ± the change in the equation of time in the particular 24 hours.

Time of one true revolution of earth = 23 hrs. 56 mins. 04·01 secs.

STANDARD TIME

If every station adhered to its own "local mean" time, the time shown by a clock would be different from that shown by all other clocks except those of the same meridian. As this would be inconvenient, "standard times," based on "standard meridians," have been laid down for use throughout various longitudinal "zones."

(i) **Greenwich Mean Time**—(indicated by the letter Z)—which is the Local Mean Time of the meridian of Greenwich, which is the Prime Meridian from which longitudes are measured. It is expressed in the 24-hour notation. If the G.M.T. is known at a particular instant, and the longitude, then the observer can find his L.M.T. at that instant, simply by adding (in Australia) his (east) long. (in time) to the G.M.T.

For example: 140° of long. corresponds to 9 hrs. 20 mins. Thus, at 1000 hours G.M.T. on long. 140° E., L.M.T. is 1920 hours.

(ii) **Western Standard Time**—(indicated by the letter H). For Western Australia—corresponding to a "standard meridian" Long. 120° E, is 8 hours in advance of Greenwich.

(iii) **Central Standard Time**
For South Australia and the Northern Territory—corresponding to a "standard meridian" Long. 142° 30′ E, is 9½ hours in advance of Greenwich.

(iv) **Eastern Standard Time**—(indicated by the letter K)
For Queensland, N.S.W., Victoria, and Tasmania, and the Mandated Territories—the standard meridian is 150° E, and the time 10 hours ahead of Greenwich.

New Zealand time is 11½ hours fast, Fiji time 12 hours fast, and Samoa time 11½ hours slow on Greenwich. "Standard" time will vary from the "local mean" time of a station according to the geographical distance of the station from the standard meridian. The difference is four minutes for each degree of longitude.

"Local mean noon" will occur after or before "standard noon," according to whether a station is West or East of the standard meridian. Local mean time (L.M.T.) is obtained from Standard Time by adding four minutes for each degree a station is East of its standard meridian or subtracting four minutes for each degree it is West of the standard meridian.

In order to find "local apparent time" from "standard time" it is necessary first to find local mean time, and then to subtract the "equation of time" corresponding to the particular day of the year.

Direction of True North by the Sun

True North can be determined as the direction of the apparent sun at "local apparent noon" when it is directly over the meridian. The standard time at which the sun will be due North or South (i.e., local apparent noon) can be calculated as follows:—

$$\begin{array}{c}\text{Local Apparent Noon}\\ \text{or}\\ \text{Standard Time}\\ \text{(shown by clocks)}\\ = 1200\\ \text{at which sun will be—}\\ \text{due North or South.}\end{array} \begin{array}{l} + \left\{\begin{array}{l}\text{4 min. for every degree}\\ \text{of longitude WEST of}\\ \text{the standard meridian}\end{array}\right\} \\ \\ - \left\{\begin{array}{l}\text{4 min. for every degree}\\ \text{of longitude EAST of}\\ \text{the standard meridian}\end{array}\right\}\end{array} \begin{array}{l} + \text{Equa-}\\ \text{tion}\\ \text{of Time}\\ \text{(as}\\ \text{above)}\end{array}$$

Example 1

Find the time at which the sun will be due North of a station longitude 142° 10′ East on 7th October. (Standard meridian is 150° East.)

Variation between standard time and local mean time $= (150 - 142^\circ\ 10') \times 4 = 7\frac{50}{60} \times 4 = 31$ and 1/3rd min. to be **added** because the station is West of the Standard Meridian.

Equation of time for 7th October = —12.

Time of local apparent noon = 1200 + 0031⅓ — 0012
= 1219⅓ E.S.T

Example 2

What is the Western Standard Time of local apparent noon at a station longitude 126° 30′ E on 22nd March. (Standard meridian is 120° E.)

Answer: 1141 hours.

Example 3

At what Central Standard Time will the sun be due North of a station longitude 139° 45′ E on 18th November. (Standard meridian is 142° 30′.)

Answer: 1156½ hours.

Within the tropics, the sun at noon may be directly overhead (or nearly so) and its direction cannot be definitely fixed. In these circumstances, it is necessary to mark the direction of the sun at equal intervals before and after local apparent noon, when the true north-south line can be obtained by bisecting the angle between the two positions of the sun

USE OF AIR ALMANAC TO DETERMINE TIMES OF SUNRISE, SUNSET, MOONRISE, OR MOONSET

By use of daily tables printed in the monthly (or quarterly) Air Almanac, it is possible to determine the times at which the upper limb of the sun or moon appears on the horizon, i.e., sunrise, sunset, moonrise and moonset.

The tables give the correct local mean time of occurrence where selected circles of latitude cross the meridian of Greenwich (longitude 0°). For a station at any longitude on a particular latitude the tabulated time may be taken as the L.M.T. of **sunset or sunrise.**

From the L.M.T. thus found, the zone (standard) time of sunrise or sunset at a station is obtained by adding (or subtracting) four minutes for every degree the station is west (or east) of the standard meridian on which its zone time is based (see example 1).

The times refer to observations made at sea level with a clear horizon. If the point of observation is above sea level a correction for height must be made to the tabulated times of sunrise or sunset. The correction is set out as a table headed "Correction for Height."

The time of one complete and true revolution of the moon in its orbit has a mean value of 27 days 7 hours 43 minutes. But during this time the earth has moved a considerable distance in its orbit around the sun. Then, if the direction of the sun in relation to the earth is taken as datum, the time for one apparent revolution of the moon around the earth (called the Synodic Period) is about 29 days 12 hours 44·4 minutes average. The "phases" of the moon are indicated at the top of each page of the Air Almanac.

When calculating **moonrise or moonset** allowance must be made for the fact that the interval between successive moonrises generally exceeds 24 hours by an amount which may exceed one hour. The tabulated values include half this amount under the heading "diff." The "diff" is used to obtain a correction which must be substracted from the times given. The correction to be applied at a particular station depends on its longitude, and is found by reference to the table on the flap of the Air Almanac. No interpolation is necessary.

When this correction has been made the correct **G.M.T.** of moonrise or moonset is obtained. The corresponding **zone** (or standard time) is found by adding (or subtracting) four minutes for every degree the station is west (or east) of the standard meridian. (See example 2.)

In each month there will be one day (near the last quarter) on which there is **no** moonrise and another (near the first quarter) on which there is no moonset. When this occurs for **the meridian of Greenwich** either the times of the corresponding moonrise or moonset for the **previous** day are given in heavy type or in parenthesis, or the time is given as greater than 24 hours, thus referring to the **next** day.

It must be stressed, however, that moonrise or moonset MAY occur on such days at places on other meridians of longitude.

When such a case arises either the **previous day's date** is entered against the time in parenthesis, or, when the time is more than 24 hours, the following day's date against the time less 24 hours. The corrections for "diff" and L.M.T. are thus made as before, care being taken to enter the date correctly. If, after calculation, the date changes to that required, the time obtained is to be taken as the time for the required day.

The rules sometimes yield the times of moonrise or moonset on the day before or after the one required. This fact emphasises the need for entering the date when copying from the tables and during calculations.

If the result gives a time on the date **succeeding** that on which the time of occurrence is desired, the date must be **decreased by one** and **twice** the "diff" (given in the moonrise or moonset table as **half** the amount by which the daily interval exceeds 24 hours) must be **subtracted** from the time obtained.

If the result gives a time on that date **preceding** that on which the time of occurrence is desired, the date must be increased by one and **twice** the "diff" must be **added** to the time. (See example 3.)

Method:

For working purposes, the use of the Air Almanac may be summarised into the following steps:—

A. **Sunrise and Sunset**

(i) Interpolate for the latitude of the station in the tabulated values of sunrise and sunset for the required day.

(ii) Add (or subtract) the correction for the height of the point of observation.

(iii) Add (or subtract) four minutes for every degree the station is west (or east) of the standard meridian.

B. **Moonrise and Moonset**

(i) Interpolate for the latitude of the station in the tabulated values for the day and enter the time and "diff" against the date.

Note.—If the date is printed in black in parenthesis the **preceding** day's date must be entered; if the time is **more** than 24 hours, subtract 24 hours and enter the next day's date.

(ii) Subtract the value in the table "Interpolation of moonrise, etc., for longitude" corresponding to the longitude and "diff."

(iii) Add (or subtract) four minutes for each degree of longitude the station is west (or east) of the standard meridian. Be careful to adjust the **date** as necessary.

(iv) If the preceding day's date and data in parenthesis has been used the result indicates that moonrise or moonset will NOT occur on the required day unless the time obtained refers to the day for which the information is required.

(v) If the date has increased—**subtract 24 hours and twice the "diff"**; if the date has decreased—**add 24 hours and twice the "diff."**

Examples:

(i) The W.S.T. of sunrise and sunset are required on 1st September, 1941, for a station at sea level, lat. 20° S., long. 114° E.

	Sunrise	**Sunset**
Lat. 20° S.	1 Sep. 0609	1 Sep. 1751
Long. 4 × (120 — 114)	+ 24	+ 24
	1 Sep. 0633	1 Sep. 1815

(ii) The E.S.T. of moonrise and moonset are required for 1st September, 1941, for a station at sea level, lat. 40° S., long. 147° E.

	Moonrise	**Diff.**	**Moonset**	**Diff.**
Lat. 40°S.	1 Sep. 13 h. 31 m.	30 m.	1 Sep. 03 h. 11 m.	26 m.
Correction for "diff"	— 25		— 21	
	1 Sep. 13 h. 06 m.		1 Sep. 02 h. 50 m.	
Long. 4 × (150 — 147)	+ 12		+ 12	
	1 Sep. 13 h. 18 m.		1 Sep. 03 h. 02 m.	

(iii) The E.S.T. of moonrise is required for 12th and 13th September, 1941, for a station at sea level, lat. 30° S., long. 153° E.

	Moonrise, 12 Sep.	Diff.	Moonrise 13 Sep.	Diff.
Lat. 30°S.	12 Sep. 23 h. 54 m.	25 m.	12 Sep. 23 h. 54 m.	25 m.
Correction for "diff"	— 21		— 21	
	12 Sep. 23 h. 33 m.		12 Sep. 23 h. 33 m.	
Long. 4 × (153 — 150)	— 12		— 12	
	12 Sep. 23 h. 21 m.		12 Sep. 23 h. 21 m.	

Advance Date

Add 24 hours plus twice "diff" + 24 h. 50 m.

14 Sep. 00 h. 11 m.
No moonrise on 13 Sep.

SECTION 2

MAIN CLOUD TYPES

See R.A.A.F. Manual 153, Section VII, pages 36-57

SECTION 3

CLOUD OBSERVATIONS

Complete, accurate, and reliable cloud observations provide a large amount of valuable information about the structure of the atmosphere. They are important synoptically because a proper recognition of cloud formations may provide a valuable index of future weather. In addition, observations of cloud movement may be used as a basis for estimating upper winds on occasions when a pilot balloon ascent cannot be made.

Cloud observations are concerned with the form, height, amount and movement of the cloud.

(1) **Form of Cloud**

At each observation it is first necessary to determine the **class** to which the cloud belongs—(upper, middle, lower, convectional or stratiform)—and then the particular type in this class. Typical forms of cloud as defined by the International Classification are relatively rare, and usually more or less intermediary forms are observed—consequently, it is necessary to note the typical form which the cloud most closely resembles.

The International Classification is based on European conditions, but the definition of cloud types (such as Cu.) remain the same in all parts of the world. It is in the frequency of occurrence of the various types that remarkable variation is seen. It is always necessary to supplement the study of International types with careful consideration of the effects of the local conditions prevailing at each station.

Correct classification will be assisted by a knowledge of the causes of cloud formations. It is obvious that the type of cloud must be correctly ascertained in order to allot it to its proper class. Errors may be avoided if due weight is given to the cause of formation of a cloud. For example, Cs. (indicative of the lifting of an air mass and approaching low pressure) should not be mistaken for Sc. (associated with fine conditions though cloudy in a subsiding air mass).

The International Weather Code for Land Stations Reports provides code figures ($C_LC_MC_H$) for describing twenty-seven forms of cloud. These figures represent variations of the ten main cloud types of the International Classification concisely, but, at the same time, sufficiently precisely to be useful synoptically and for "ground reports." The code figures to be used are those for the specifications which most nearly represent the state of the sky at the time of observation.

It is essential that trainees should acquire a mental picture of the states of the sky represented by each of the code figures.

It must be stressed that cloud observations MUST NOT be confined to the "synoptic hours." The reliability and ease of observation are very greatly increased by keeping a continual "watch" on the sky. Difficulties which might be associated with a single cloud observation are nearly always avoided by maintaining a sequence of about half-hourly observations which will show the development and changes in cloud forms.

In order to make them as useful as possible, the observations should include all available information. For example, it is necessary to indicate whether clouds are "deep" or "thin." Observations of low cloud should include references to the distance and direction of breaks in a continuous sheet, or a tendency to broken cloud conditions or the reverse.

X An observer on the ground can record only what he sees; there may be sheets of cloud at various levels, for example Cs., As., Ns. may completely cover the sky, while on some occasions small breaks in the sheets of low cloud may reveal the presence of Cs. above.

While unnecessary for aviation reports, observations of subtypes such as Mammatus or Castellatus afford useful synoptic information as to the stability of the atmosphere.

(2) **Height of Cloud**

While it is the height of the base of the cloud (especially low cloud) which is more generally observed, it is important in many cases to determine the depth of the cloud as well. The height of the base of the cloud may be measured by observation of a pilot balloon released to rise with a fixed rate of ascent, or in dusk or darkness with a cloud searchlight.

When using a pilot balloon it is necessary only to note the time that elapses between the release of the balloon and its disappearance in the lower surface of the cloud. If the wind is at all strong it is unsatisfactory to rely upon the naked eye, and the balloon should be observed with a theodolite. care must be taken to distinguish between cases in which the balloon is obscured by cloud at some lower level drifting across the field of view from its disappearance in the base of a cloud.

The cloud searchlight cannot be used satisfactorily in strong daylight; even in darkness the beam may be diffused by rain.

Sometimes (as at stations such as Hobart) it will be possible to fix the height of the cloud base by reference to its position on an adjacent hillside, the heights of whose features are known.

Generally it will be necessary to estimate the height of the base of the cloud. This is largely a matter of experience of the various appearances of the clouds in particular localities. Observers should take every opportunity of checking the estimates by measuring with pilot balloons and by comparing notes with pilots. The estimates should be based on the past records, and may, in the first instance, be made by reference to the height at which the main types are formed.

HEIGHTS OF THE BASE OF CLOUDS

Form of Cloud	Usual Heights	Remarks
Stratus	500-2,000 feet	Sometimes practically down to the surface; sometimes as high as 4,000 feet.
Stratocumulus . .	2,000-5000 feet	Sometimes as low as 500 feet or as high as 8,000 feet.
Cumulus	2,000-5000 feet	Sometimes as low as 1,000 feet or as high as 8,000 feet.
Cumulonimbus . .	2,000-5000 feet	Sometimes as low as 1,000 feet; in the tropics the tops may be as high as 30,000 feet; in Victoria the tops may reach 16,000 feet.
Nimbostratus . .	500-2,000 feet up to A.s.	Sometimes practically down to the surface; sometimes as high as 4,000 feet.
Altostratus, Altocumulus . .	Heights usually between 6,500 and 20,000 ft.	For some purposes the height may be taken as 16,000 feet.
Cirrus, Cirricumulus, Cirrostratus . .	Heights usually between 20,000 and 40,000 feet.	

Every opportunity should be taken to acquire a knowledge of the diurnal and seasonal variations of the heights of clouds at particular stations. In general, each type of cloud is lower in winter than in summer; lower over humid than over desert regions; lower over oceans than over continents; lower over plains than over hills, and lower with increase of latitude.

Aviation reports must include the height of the base of clouds, those whose base is below 2,000 feet being given to the nearest 100 feet, and those above 2,000 feet to the nearest 500 feet up to 8,000 feet. In cases where fragmentary cloud is observed below a continuous sheet of low cloud, the "height of low cloud" refers to the main lowest sheet of cloud and not to the fragmentary cloud which is reported as "lower patches." If several layers of cloud below 8,000 feet are observed, the height of low cloud refers to that of the lowest sheet, extending over ~~4/10~~ths or more of the sky.

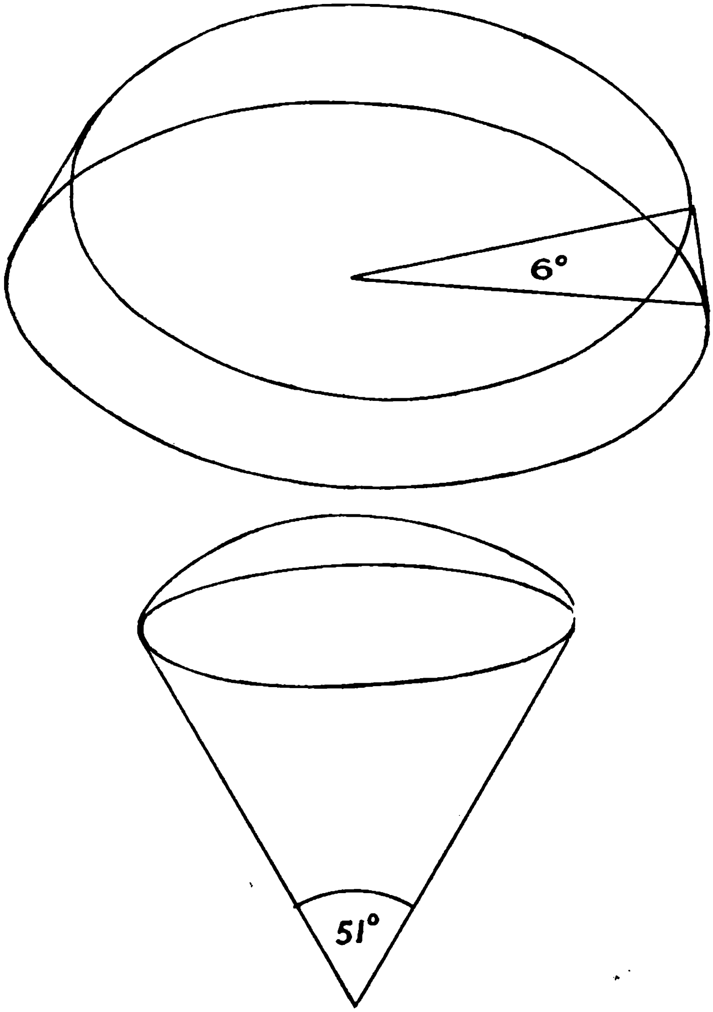
(3) **Amount of Cloud (or Cloudiness)**

Cloudiness is observed as the amount of the sky covered, estimated by eye and expressed on a scale of eighths ~~tenths~~. On this scale ten represents a sky totally covered by cloud in which no particles of blue sky are visible; and "0" an entirely cloudless sky. It is required to estimate the number of ~~tenths~~ of the area of the sky which could be covered by the clouds present supposing them moved up to each other so as to form a continuous sheet.

In estimating cloud amount, the observer should subdivide the sky into quadrants by means of diameters at right angles to each other. An estimate (on the scale 1-~~10~~ 8) is then formed for each quadrant separately and the figure finally recorded is

the value of the four numbers so obtained. The direction of the dividing diameters should be selected to give convenient subdivisions of the prevailing cloud canopy. The following is an aid which might be useful: If the hand is held out at arm's length and the wrist bent so that the palm of the hand faces the observer, the hand from the wrist to the tips of the fingers covers roughly 1/100th of the sky. The hand must be open but the fingers should be kept together and not spread apart.

Care must be taken not to over-estimate the amount of sky covered by clouds near the zenith, or to under-estimate cloudiness near the horizon. At the zenith, 1/10th of the sky is represented by a solid angle of about 51°. One-tenth cloudiness around the horizon is covered by an angle of elevation of 6°.



The amount of each group (upper, middle and lower), as well as the total amount of cloud, must be estimated, e.g., upper ~~2/10~~, middle ~~2/10~~, lower ~~4/10~~.

The amount of low cloud should be estimated separately by imagining that every other visible form of cloud is replaced by blue sky. The amount of patches of cloud below a main low cloud sheet will also be reported in ~~tenths~~. 8

On some occasions when cloud is present at different levels, it is possible to observe amounts of each type whose sum is greater than ~~10/10~~. However, the "total" amount of cloud cannot be **reported** as more than ~~10/10~~.

In cases of fog when the sky is discernible, the cloud is recorded and reported **as if no fog were present.** If cloud can be seen through the fog, the amount should be estimated as well as possible. If the sun, moon or stars can be seen through the fog and there is no evidence of cloud above the fog, the amount of cloud should be recorded as "0," irrespective of the horizontal thickness of the fog. If the vertical thickness of the fog is so great that it is impossible to tell whether there is cloud above it (as, for example, in daytime when the sun is quite invisible) the cloud amounts should be reported by code figure 9.

Cloudiness may be recorded descriptively in the following terms:

Clear sky—when there are no clouds present or less than 1/~~10~~th of a sky is covered by cloud.

Scattered—when detached clouds cover from 1/~~10~~th to 5/~~10~~ths.

Well broken—when breaks can be seen in a layer so that ~~6/10~~ths or ~~7/10~~ths of the sky is covered.

Broken—when ~~8/10~~ths of the sky is covered.

Almost overcast (or overcast with breaks)—when 9/~~1~~0ths of the sky is covered (the position of the breaks must be reported).

Overcast—when the sky is completely overcast.

Observations of clear and overcast skies are much more frequent than those of intermediate values. The reason lies in the fact that overcast and clear skies are stable; while a partly half clouded sky is one in continual change. In addition, an overcast or clear sky may persist for a long time, but a changing sky may vary between 0 and 10/10ths cloudiness, giving a wide range at the fixed hours of observation.

(4) Movement of Cloud

Precise measurement of cloud movement may be made by using a "nephoscope" (of the mirror or comb type) or a pilot balloon theodolite. While the measurement of cloud, particularly of medium and high cloud, should be observed whenever possible, generally cloud movement will be estimated.

While long experience and a close study is required to even roughly estimate the speed of cloud movement, the direction may be reasonably well fixed.

The direction of cloud movement may be estimated by observing the motion of the clouds past a fixed line at right angles (such as the walls or spoutings of a building) whose orientation is known. During the observations the head must be rested against a fixed object. If possible lines running North-South and East-West should be selected to observe the components of the cloud movement; the direction can generally be defined in terms of the 16 points of the compass.

(5) Diurnal Variations of Cloud

Because it is affected directly by radiation, stratified cloud tends to form by night and disappear by day. Owing to its dependence on vertical motion in an unstable atmosphere cumuliform cloud tends to increase by day and disappear by night. Fine weather cumulus may be transformed, especially towards evening, into a sky characterised by banks of low strato-cumulus, or it may become extended quite near to its base and may coalesce into an almost continuous layer. Thunderstorms have a marked maximum occurrence in the late afternoon or early evening, and are rare in the early hours of the morning.

The diurnal variation of cloud amount is irregular. On the whole it shows a minimum just about 2200 hours. The time of the maximum varies with the seasons, occurring before mid-day in winter and after mid-day in summer. The afternoon maximum in summer is largely due to the formation of clouds of the cumulus type.

This tendency normally holds at inland stations (such as Bendigo) whose weather is characterised by clear mornings and cloudy afternoons. However, it may be reversed on account of local effects at coastal stations. In Melbourne, for example, cloudiness has a maximum at 0700 with a tendency to clear in the afternoon, and a minimum occurring at 2200 hours.

SECTION 4

OBSERVATION OF WEATHER AND VISIBILITY

1. PAST AND PRESENT WEATHER

Under the term "Weather" are included observations of the state of the atmosphere usually referring to phenomena which cannot be expressed quantitatively. That is, the observation of "Weather" is concerned with such points as whether rain is actually falling, or the presence of obscuring matter in the atmosphere giving rise to fog, mist, haze, etc. For the most part, these phenomena indicate modifications in the condition of the water vapour in the atmosphere.

Observations should be made with reference to the "International Weather Code for Land Station Reports."

Attention is drawn to the interpretation of terms used in describing precipitation.

(a) Drizzle-Misty Rain

Drizzle is not "rain in small amounts," but "precipitation in which the drops are very small." It implies the slow fall of numerous minute drops. Drizzle falls from stratus and stratocumulus cloud almost exclusively, and is frequently orographic. It, generally, only occurs with overcast sky and low cloud of appropriate type, and may be intermittent or continuous.

Slight rain, on the other hand, is precipitation in which the drops are of appreciable size (they may even be large drops), but are relatively few in number. Observers should decide from the size of the drops whether the precipitation is drizzle or rain; and, from the combined effect of the number and size of the drops, whether the precipitation is slight, moderate or heavy.

(b) Continuous Precipitation

In reports of past weather, a break of only ten minutes duration in a period of continuous rainfall can be disregarded, but a break of half an hour must be taken into account. The duration of precipitation necessary to justify the use of the word "continuous" in reports of weather cannot be rigidly fixed. If it rained without a break for two hours it should undoubtedly be described as "continuous rain." If it rained for only half an hour it would not be called continuous rain.

(c) Intermittent Precipitation and Passing Showers

There is a difference in the type of weather described as "intermittent rain" and "passing showers." Showery precipitation is characterised by the suddenness with which it starts and stops, and its rapid changes of intensity. In general, showers are of short duration, and the intervals between the showers are usually

characterised by definite clearances in the sky. Often the aspect of the sky changes between dark, threatening clouds, and clearings of the sky. The clouds which give the showers are isolated. The precipitation does not usually last more than 15 minutes, although it may sometimes last for half an hour or more.

"Intermittent precipitation," on the other hand, usually lasts for a longer time than showers, and the weather between the periods of precipitation is usually cloudy or overcast. It should, however, be realised that weather between periods of intermittent precipitation may be clear.

(d) **Fog, Mist and Haze**

The terms fog, mist, and haze are used to indicate a diminution in the transparency of the atmosphere due to suspension in the lower layers of small particles. The particles may be either solid or liquid. The terms fog and mist are generally regarded as applicable to occasions when the obscurity is due mainly to water particles, the word "haze" being applicable when dust particles are the chief cause of the lack of transparency. The observer has no definite criterion for determining whether he is observing dust or water particles, but the humidity of the lower atmosphere as indicated by the readings of the dry and wet bulb thermometers will afford some guide. If the depression of the wet bulb is slight, it may be assumed that water droplets predominate so that the terms "mist" or "fog" are appropriate; on the other hand, when there is a large difference between the wet and the dry bulbs, the term "haze" is appropriate. The distinction between fog and mist is one of degree, the term "fog" being reserved for occasions of more marked diminution of transparency.

High Fog. It occasionally happens near industrial centres that heavy smoke-laden clouds overhead cut off practically all daylight, though the visibility in the surface layers of the atmosphere, as judged by the appearance of distant lights is but little influenced. Such conditions may be described as "high fog," and should be carefully noted, but they do not comply with the conventional definition of fog given above In such circumstances the observations of visibility should be made according to the standards adopted for work at night. In statistical summaries occasions of high fog are not included. The international symbol ≡ should not be used.

Attention must also be drawn to the difference in the reporting of precipitation within the hour preceding the time of observation in the present weather (ww) code and the use of the past weather (W) code.

2. HORIZONTAL VISIBILITY

It is extremely important to a pilot to know how far he will be able to see during take-off, during the flight, and in landing at his terminal.

A scale of "visibility" has been devised, based on the maximum distance at which an object is visible. In practice a number of objects are selected as nearly as possible at standard fixed distances from the observing station, the distances increasing roughly in such a way that each is nearly double the next smaller distance. The determination of the most distant object of the series which is visible on any given occasion constitutes the observation of "visibility."

While visibility is mainly effected by the amount of solid or liquid particles present in the atmosphere it also depends upon:—

(1) the lighting of the object viewed;

(2) the lighting of the background;

(3) the light reflected from and refracted in the atmosphere.

The visibility scale is set out in the "International Weather Code for Land Station Reports" on a scale 0-9, representing the limits of visibility at 55, 220, 550, 1100 yards, 1¼, 2½, 6¼, 12½ and 31 miles.

It is necessary to have a criterion as to what is meant by an object being visible. It is often possible to see "something" without being able to see what it is, unless one knows beforehand what it is; in such a case the object is not visible according to the meteorological convention. An object is therefore to be regarded as "visible" if it can be distinguished by eye; if the object is a tree and it can be distinguished as a tree, it is to be noted as "visible."

The ideal object should subtend at the observer's eye ten minutes of arc in length and 2½ minutes in breadth. At a mile this would give a measure of 15 feet by 4 feet. Such objects as church spires or factory chimneys would be satisfactory. It is very desirable that the objects should be on the sky line and well illuminated. If objects at the precise distances of the table are not available an attempt should be made to secure them at as nearly these distances as possible. For the purpose of routine, observations should be confined to one and the same series of standard objects.

In making estimates of the visibility in cases where the farthest object is only a comparatively short distance from the observer, it will be helpful, in the interests of accurate reports, if the observer notes the sharpness with which the reference objects stand out. When objects at some distance stand out sharply with

little blurring of colour, it may be taken that the atmosphere is free of haze and the visibility quite high. On the other hand if the objects are blurred or indistinct and seem to have a grey or purplish hue the presence of haze or other obstructions is indicated with a consequent reduced visibility.

All observations of visibility should be taken from a point where a view of the entire horizon may be had; or, if this is not practicable, the observer should move about in such a manner as to obtain a view of the horizon in all directions. This observation point should be on the ground, if at all practicable; otherwise, it should be made at the lowest point above the surface at which a satisfactory observation can be made.

The distance of visibility corresponding to the code figure reported should prevail over half or more of the horizon—if the visibility in a particular section of the horizon is much poorer than that prevailing in other directions, a note covering the variation should be included in the report.

Visibility at Night

In the case of observations made at night, the visibility scale will be used to denote as nearly as possible the same degree of atmospheric obscurity as in daylight observations. Stationary lights at known distances will in general provide the basis of estimation, but it is usually difficult to get a selection of fixed lights at the appropriate distances. Care must be taken due to the difficulty raised by the fact that a very bright light may cause an appearance of brightness in its direction, or show light in the sky in a state of atmospheric obscurity which would not permit the observer to see the actual source of light in the same way that he can see one of his daylight objects. Apart from the use of lights a careful observer can derive a considerable amount of information as to night visibility from a general inspection. It is surprising how much can be seen even on a fairly dark night, e.g., a distant range of hills may be made out against the sky line in circumstances which indicate that in daylight an object at that distance would be "visible."

The observer should keep in mind that the absence of daylight does not materially affect the visibility as such, this being actually a measure of the transparency of the atmosphere. Thus, any considerable daily rise and fall of the values of visibility given for hours of daylight and darkness should be avoided. However, diurnal changes of wind and atmospheric stability may cause some variation in the visibility between hours of daylight and darkness. The reporting of visibility conditions during darkness or twilight in the lower figures of the scale merely because standard reference objects cannot be seen is incorrect. It is preferable to

determine visibility along a line nearly at right angles to the line of sight from the observer towards the sun or bright moon. Lights used for the determination of visibility at night should be of appropriate candle power as set out in the International table:

Code Fig.	Daylight Observations	Night Observations: If lights at the same distances as objects are to be used they must be of the candle power shown below	Night Observations: If lights of fixed intensity of 100 candle power are used they must be at the following distances: Object Distance	Distance for 100 c.p. light
		c.p.		
0	Objects not visible at 55 yds. (dense fog)	0·13 at 55 yds.	55 yds.	110 yds.
1	Objects visible at 55 yards but not at 220 yds. (thick fog)	0·9 at 220 "	220 "	370 "
2	Objects visible at 220 yds. but not at 550 yds. (fog) ..	3·5 at 550 "	550 "	810 "
3	Objects visible at 550 yds. but not at 1100 yds. (moderate fog)	10 at 1100 "	1100 "	1470 "
4	Objects visible at 1100 yds. but not at $1\frac{1}{4}$ miles (mist, haze, very poor visibility)	35 at $1\frac{1}{4}$ miles	$1\frac{1}{4}$ miles	$1\frac{1}{4}$ miles
5	Objects visible at $1\frac{1}{4}$ miles but not at $2\frac{1}{2}$ miles (thin mist, poor visibility)	100 at $2\frac{1}{2}$ "	$2\frac{1}{2}$ "	$2\frac{1}{2}$ "
6	Objects visible at $2\frac{1}{2}$ miles but not at $6\frac{1}{4}$ miles (moderate visibility)	420 at $6\frac{1}{4}$	$6\frac{1}{4}$ "	$4\frac{3}{4}$ "
7	Objects visible at $6\frac{1}{4}$ miles but not at $12\frac{1}{2}$ miles (good visibility)	1250 at $12\frac{1}{2}$ miles .	$12\frac{1}{2}$ "	$7\frac{1}{2}$ "
8	Objects visible at $12\frac{1}{2}$ miles but not at 31 miles (very good visibility)	4500 at 31 mls.	At greater distances 100 c.p. is not suitable.	
9	Objects visible at 31 miles or more (excellent visibility) ..	From 20,000 at 93 miles.		

3. VERTICAL VISIBILITY

The vertical visibility of the atmosphere as observed from aircraft is estimated in two ways:—

(a) **"Oblique visibility"** which is reported as the distance in miles measured on a map of the farthest object on the surface which can be recognised; and

(b) **"Vertical visibility"** which is based on the apparent colour of objects on the surface and reported on a scale 0-5.

VERTICAL VISIBILITY CODE

Scale No.	Description	Definition
5	Excellent ..	Ground objects sharp and clear, colours undimmed.
4	Good	Details of ground objects easily distinguishable, colours dimmed a little.
3	Fair	Haze apparent, details of objects harder to distinguish.
2	Indifferent ..	Details of objects not visible although outlines still apparent. Definite blueish haze over everything, through which only reds and yellows really stand out.
1	Bad	Only larger objects on ground recognised. Colour distinctions hardly apparent.
0	Nil	Nothing on ground visible at all.

SECTION 5

OBSERVATION OF WIND AND RAIN

A. OBSERVATION OF WIND

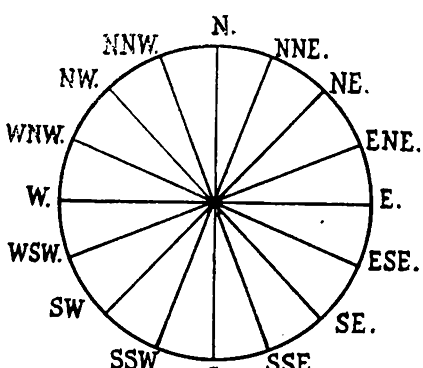
Having a special bearing on landing conditions, offering a useful clue to distribution of atmospheric pressure and aiding (to some extent) the forecasting of local weather conditions, the wind near the surface of the earth is of special interest. It is specified by direction and velocity.

Wind near the surface is affected by many local influences, and the task of determining the direction and velocity representative of the general circulation in a particular locality is a difficult one. The observation must be made clear of minor irregularities of the ground, buildings and other obstructions to the main air stream as these tend to set up local eddies whose apparent direction may be widely different from those of the truly representative wind. Although wind direction and velocity may be reliably estimated by a trained observer, a well exposed and properly constructed anemometer is the best indicator. In order to make a network of observations comparable, specifications have been made definite by directing that the velocity and direction should be measured at a height of 33 feet (10 metres) above the ground or the highest part of a building.

(i) Direction

After the determination of "true north" at a station convenient reference points marking the "cardinal directions" should be selected.

The wind is specified according to the **true** direction from which it blows. The direction of the surface wind is observed and reported to pilots in terms of the 16 compass points:—

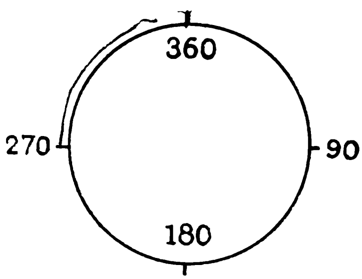


In weather messages these are coded in the International Code:—

International Code	Direction	International Code	Direction
00	Calm	16	S.
02	NNE.	18	SSW.
04	NE.	20	SW.
06	ENE.	22	WSW.
08	E.	24	W.
10	ESE.	26	WNW.
12	SE.	28	NW.
14	SSE.	30	NNW.
		32	N.

The direction of upper wind is determined in **degrees** on a scale 0-360 from **true** north through **east.**

In this case the observations are coded by approximating the direction to the nearest ten degrees, each direction being specified by two figures: 01, 04, 16, 23, 33, for example, indicating that the upper winds are blowing from 10, 40, 160, 230, and 330° respectively.



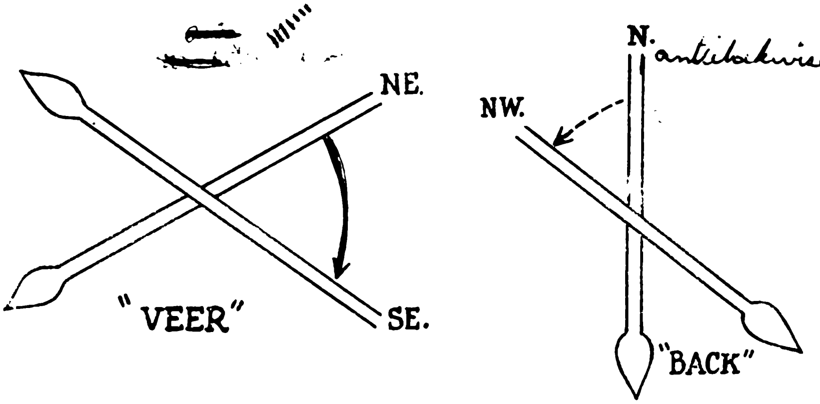
If it is necessary to refer to upper wind directions in terms of compass points, the following convention is used:—

35, 36, 01	=	N.	20, 21	=	SSW.
02, 03	=	NNE.	22, 23	=	SW.
04, 05	=	NE.	24, 25	=	WSW.
06, 07	=	ENE.	26, 27, 28	=	W.
08, 09, 10	=	E.	29, 30	=	WNW.
11, 12	=	ESE.	31, 32	=	NW.
13, 14	=	SE.	33, 34	=	NNW.
15, 16	=	SSE.			
17, 18, 19	=	S.			

If the direction of the surface wind cannot be obtained by means of an anemometer, it may be indicated by a wind vane, a wind sock or the movement of smoke, grass, leaves, etc. A wind vane is not reliable unless it is of correct design, while a wind sock may not give the proper direction unless the wind velocity is 10 m.p.h. or more.

When the direction changes the wind is said to "**veer**" or "**back**" according as the change is in a clockwise or counter clock-

wise direction. For example, the wind "veers" when it changes from N.E. to S.E. and "backs" when it changes from N. to N.W.



In Southern Australia the wind usually "backs" when a cold change arrives.

(ii) **Velocity**

For aviation advices, the velocity of the wind is reported in ~~miles~~ per hour. For other purposes the "force" of the wind is conveniently expressed by the "Beaufort Scale." This scale of wind force was originally devised by Sir Francis Beaufort in 1808 on the basis of the amount of canvas the man-of-war of that period could carry with different winds. Each Beaufort number has now been assigned a definite range of wind speeds and the specifications have been conveniently expressed for observation on land and sea.

TABLE OF SPECIFICATIONS FOR THE BEAUFORT WIND SCALE

Beaufort No.	Description Term	Limits of Speed At 10m. (33ft.) in the open		Specifications	
		m.p.h.	Ft./sec.	Land	Sea
0	Calm ..	Less than 1	Less than 2	Calm; smoke rises vertically.	Sea like a mirror.
1	Light air ..	1-3	2-5	Direction of wind shown by smoke drift, but not by wind vanes.	Ripples with appearance of scales are formed, but without foam crests.
2	Light breeze	4-7	6-11	Wind felt on face; leaves rustle; ordinary vane moved by wind.	Small wavelets still short but more pronounced. Crests have a glassy appearance and do not break.

TABLE OF SPECIFICATIONS FOR THE BEAUFORT WIND SCALE—Continued

Beaufort No.	Description Term	Limits of Speed At 10m. (33ft.) in the open m.p.h.	Ft./sec.	Specifications Land	Sea
3	Gentle breeze ..	8-12	12-18	Leaves and small twigs in constant motion; wind extends light flag.	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.
4	Moderate breeze ..	13-18	19-27	Raises dust and loose paper; small branches are moved. Flag straight.	Small waves becoming longer; fairly frequent white horses.
5	Fresh breeze	19-24	28-36	Small trees in leaf begin to sway; crested wavelets form on inland water.	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray.)
6	Strong breeze ..	25-31	37-46	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty; flag rises.	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray.)
7	Moderate gale ..	32-38	47-56	Whole trees in motion; inconvenience felt when walking against wind.	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.
8	Fresh gale..	39-46	57-68	Breaks twigs off trees; generally impedes progress.	Moderately high waves of greater length; edges of crests begin to break into the spindrift. The foam is blown in well-marked streaks along the direction of the wind.
9	Strong gale.	47-54	69-80	Slight structural damage occurs (chimney pots and slates removed).	High waves. Dense streaks of foam along the direction of the wind. Sea begins to "roll." Spray may affect visibility.

Table of Specifications Etc., Continued

Beaufort No.	Description Term	Limits of Speed At 10m. (33ft.) in the open: m.p.h.	Ft./sec.	Specifications: Land	Sea
10	Whole gale..	55-63	81-93	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	Very high waves with long overhanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock - like. Visibility affected.
11	Storm ..	64-75	94-110	Very rarely experienced; accompanied by widespread damage.	Exceptionally high waves (small and medium - sized ships might be for a time lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.
12	Hurricane..	Above 75	Above 110		The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.

When estimating wind force it is necessary to avoid being influenced by personal physical sensations. The effects of the wind on various objects (trees, grasses, wind mills, etc.) should be noted and reference made to the specifications of the table.

(iii) **Fluctuations in Wind Velocity**

Especially near the surface of the earth, winds do not consist of a steady flow of air but of a succession of "gusts" and "lulls" caused by frictional and obstructional interference with the free flow of the air stream, so that all winds are actually "gusty." These gusts and lulls are clearly shown as fluctuations on the trace of the anemograph.

The difference between the wind velocity at a "gust" and that at a "lull" is called the **"Range of Gustiness."** The "range of gustiness" will vary considerably from time to time, from place to place and with different wind directions. For synoptic purposes the velocity of the wind that is reported is the **mean** of the velocities at the gusts and lulls. The description "gusty" should supplement the force of the wind if the "range of gustiness" is abnormally large. ~~In the International Code, 33 is added to the code number for wind direction if the gustiness of the wind has been unusually marked for that direction during the hour preceding the time of observation.~~

"Gusts" may have disastrous effects on aircraft when landing and it is important that pilots should be given the range of gustiness as well as the mean wind velocity when they are approaching an aerodrome to land.

The term "gust" must not be confused with "squall." The word "gust" is limited to the comparatively rapid fluctuations in the strength of the wind near the surface of the earth which are the result of mechanical interference with the steady flow of air. "Squalls" are attributable to meteorological causes. They are blasts of wind occurring suddenly, lasting for some minutes, and dying away as suddenly. They are usually accompanied by a change of wind direction, a rise in pressure and a fall in temperature. ~~In the International Code a squall is indicated by adding 67 to the code figure for wind direction and code figure 14 or 15 for present weather, if any other figure is not more appropriate.~~

(iv) **Diurnal Variation of Wind**

Especially in clear summer weather winds show a tendency to increase in speed and to "back" between sunrise and mid-afternoon, and to decrease and "veer" towards evening. Thus a south-westerly in the early morning may change to south-south west by early afternoon and later become south-westerly again. The change in direction, however, may be masked by changes of atmospheric pressure, usually land and sea breezes, etc. The "gustiness" of the wind increases during the morning and early afternoon and decreases to a smoother flow during the night. These changes are again apparent on the anemograph chart. On cloudy days the diurnal variation tends to disappear. [illegible] and the variation will be uneven.

B. **OBSERVATIONS OF RAINFALL**

(v) "Rainfall" is the total product of precipitation or condensation falling on a horizontal surface from the atmosphere, as received and measured in a rain gauge. In Australia rainfall is measured in "points" and inches, while the International unit is the millimetre:—

100 points = 1 inch = 25·4 mm.
1 mm. = 4 points.

An "inch" of rain is the amount which, falling on a horizontal surface, will cover it to a depth of 1 inch. It is interesting to note that—

1 inch = 100 tons of water per acre (approx.).
= 65,000 tons per square mile (approx.).

A rain gauge consists of a copper funnel of 8 inches diameter with a bevelled horizontal rim, covered to prevent loss by evaporation, and raised 12 inches above the ground to prevent splashing. The specifications for its exposure are given on page 15 A.O.H.

The rainfall is measured by pouring the water received by the funnel into a glass measure, graduated (according to the relative diameters of the gauge and the measure) into "points." Usually the measure is kept in the gauge in such a position that it receives water falling directly from the funnel. When reading the measure it should be held near the top so that it hangs vertically, and the surface of the water appears on the same level as the eye. The bottom of the "meniscus" should be read off the scale to the nearest division, half divisions, e.g., (22·5), being approximated to the nearest odd division. A "trace" of rain is reported when rain has actually fallen and the gauge is empty or records less than 0·5 point.

After heavy rain, there may be more than enough to fill the measure. In these cases, pour in enough water to nearly fill the measure (say, 49 points), read, write down, and pour water into a clean dry jug. Repeat until the residue is less than 50 points, each time writing down the amount measured. The whole measurement should be repeated to ensure there is no mistake in counting the number of half inches. The measurements must then be added to find the amount of rainfall, e.g., 49 + 47 + 47 + 24 = 167 points.

When the precipitation has occurred in the form of snow or hail, or if the water in the gauge has frozen, the funnel and the receiver should be taken indoors and gently warmed until the ice or snow melts, when the measurement is made in the usual way. One foot of snow is roughly equivalent to 1 inch of rain, but the relation varies greatly.

(vi) **Pluviograph**

Rainfall is measured automatically by a "pluviograph." In the "float" type (used in Australia) the funnel discharges into a receiver containing a cylindrical float with a rod carrying a pen arm, so that, as the float rises (after the receipt of rain water) the pen is lifted on the scale of the recording chart. A glass siphon is adjusted to empty the receiver automatically when 40 points have been received, and to cause the pen to be returned to the zero line of the chart.

A full description of the instrument together with directions for its maintenance is given on pages 76-78 A.O.H.

THE STATE OF THE SEA

The state of the sea is reported according to the International Code specifications. The following table is given as an indication of the description of the sea, and the code figures:—

Code Figure	Description of Sea	Abbreviations	Height of Waves (in feet)	Effect
0	Calm (glassy) . .	C	0	No waves breaking on beach.
1	Calm (rippled) . .	C	0	
2	Smooth (wavelets)	S	0-$\frac{1}{2}$	Slight wavelets breaking on beach.
3	Slight	Sl	$\frac{1}{2}$-2	Rocks buoys and small craft.
4	Moderate	M	2-5	Sea becoming furrowed.
5	Rough	R	5-9	Deeply furrowed sea.
6	Very rough . .	VR	9-15	Much disturbed with rollers having deep fronts.
7	High	H	15-24	Rollers having steep fronts (damage to foreshore).
8	Very High	VH	24-36	Towering seas.
9	Phenomenal . .	Phen.	36	Precipitous sea experienced only in hurricanes.

Generally, in sheltered waters, the state of the sea would rarely be above code figure 5. The code figures 6 or 7 would be reported only in exceptional circumstances, such as during prolonged gales from an exposed direction. Code figures 8 or 9 would occur only in the open ocean.

At shore observing stations, the only guide can be the description of the sea's surface, the height of the waves and, to some extent, the effect of the sea. The effect of the sea varies so much in different localities, and is modified so much by streams, currents, tides and swell, that it is difficult to lay down definite rules. However, the general effects as given in the above table could be used as a guide.

RELATION OF STATE OF THE SEA AND WIND FORCE

The force of the wind can only be related to the state of the sea in the open ocean. In straits, bays, or in the sea areas, from 2 to 5 miles from the shore, it is difficult to attempt to relate force of wind with the state of the sea. In these areas, the direction of the wind may have a greater effect on the state of the sea than the force of the wind. An off shore wind of gale force, for instance, has the effect of flattening seas for a considerable distance from the shore, and the stronger the wind the further out to sea the relative smoothness extends. This is very noticeable with strong westerlies on the New South Wales coast, and strong easterly winds in the Bass Strait area.

In the open sea, however, the state of the sea may be related to the wind as follows:—

Wind (Beaufort Force)	**Sea**
0	Calm.
1–3	Smooth.
4	Slight.
5	Moderate.
6–7	Rather rough.
8	Rough.
9–12	Very rough.

The state of the sea in an open situation is very closely related to the strength of the wind at the same time. No universally applicable rule for relating wind and sea can be laid down, but the above table can be used in average circumstances.

STATE OF SWELL IN OPEN SEA

Careful distinction should be made between sea and swell, sea being the waves caused by the wind at the place and time of observation, while swell is longitudinal wave motion due to past wind or wind at a distance. Swell is wave motion in the ocean caused by a disturbance which may be at some distance away; the swell may persist after the originating cause of the wave motion has ceased or passed away. It often so continues for a considerable time with unchanged direction, as long as waves travel in deep water. The height of the waves rapidly diminishes, but the length and velocity remain the same, so that the long low regular undulations, characteristic of swell, are formed. Swell is often observed to have a wave length greatly in excess of that of waves seen during a storm: the probable explanation is that the longer waves are then masked by shorter and steeper storm waves.

Properly speaking swell can only be observed in the ocean 500 miles from land in the absence of streams, and away from shoals. On the other hand, observations of swell made near a coast are useful for many purposes, particularly for handling shallow water craft, seaplanes, aircraft carriers, troop ships, etc. Swell observations are also useful as denoting the direction in which sea disturbance due to tropical cyclones or other storms has taken place.

The direction from which the swell comes should be noted to the nearest compass point.

A short swell means a swell where the length or distance between each successive top of swell is small.

A long swell means a swell where the length or distance is large.

A low swell means a swell where the height between the lowest and highest part of the swell is small—less than 2 metres.

A moderate swell means a swell where the height is moderate—from 2-4 metres.

A high swell means a swell where the height is great—greater than 4 metres.

The term "confused" is used when state of the swell is non-measurable or indistinct (e.g., crossing swells of nearly equal heights). It might also be occasioned by current, tidal streams, sudden shift of wind.

SECTION 6

TEMPERATURE AND HUMIDITY

A. OBSERVATION OF TEMPERATURE

Reports of temperature which are truly representative of the air over a given area are most important as, even in a fairly close network of stations, each one must serve for several thousand square miles. For example, if stations are 60 miles apart the readings made at each station are taken to be representative over 2700 square miles. In addition the reduction of barometric pressure to mean sea level is to a large extent dependent upon its reliability.

1. Exposure of Thermometers

As air conducts heat slowly but freely permits radiation, the thermometer which measures the temperature of the air must not be exposed too near to the ground nor close to surrounding buildings, or insolational heating during the day, and radiational cooling at night, may give rise to abnormally high or low temperatures. The thermometer should be shielded from the direct rays of the sun, and must be properly ventilated, so that it will indicate the true air temperature unaffected by direct solar radiation.

Local effects may be eliminated by exposing the thermometer 20 to 30 feet above the surface of the ground, or by placing it in a strong current of air (as in the whirling and aspirated psychrometers) or by arranging it in a suitable shelter.

2. The Stevenson Screen

The normal exposure for thermometers is the "Stevenson Screen" which should be placed in a 20 feet or 30 feet plot of level ground covered with short grass, freely exposed to the sun and wind, with its opening facing south. The nearest obstruction should not be nearer to the screen than 2½ times the height of the obstruction, so that it is not shaded by trees or buildings. The "temperature of the air" is taken to be that indicated by a mercury-in-glass thermometer properly exposed in a correctly constructed Stevenson screen with the bulb of the thermometer 4 feet above short grass. 1·5 metres/second.

3. Reading Thermometers.

When reading the thermometer care should be taken to **avoid shielding the stem from the wind.** As the thread of mercury is not in the same plane as the scale inscribed on the glass stem errors of parallax will arise unless it is ensured that **the line joining the eye to the top of the mercury thread is at right angles to the stem.** The temperature should **be read as quickly as possible to**

0·1° F. When a thermometer reading is entered to a whole degree it should be the nearest degree, e.g., if the reading be between 49° and 50°, but nearer 50° than 49°, 50° should be entered. Where the corrected reading comes half way between two degrees, i.e., at ·5, **the odd degree should be entered in the return.** For example, corrected readings of 48·5 and 49·5 would both be entered as 49°, while 50·5 and 51·5 would both be entered as 51°.

All temperature readings must be carefully checked especially to ensure that there is not **an error of 5° or 10°.**

4. **The Dry Bulb Thermometer.**

The most commonly used type of thermometer for measuring the temperature of the air is the mercury in glass; other types are the mercury in steel, the alcohol thermometer, electric resistance thermometers and thermocouples. The mercury in glass thermometer is hung vertically in a Stevenson Screen. It must be **kept clean;** in particular no deposit should be allowed to accumulate on the bulb. The presence of moisture will cause it to behave like a wet bulb thermometer.

5. **The Wet Bulb Thermometer**

This thermometer consists of a mercury-in-glass thermometer with its bulb covered with clean muslin kept moist by attaching a few threads of darning cotton 3 to 6 inches long, which dips into a small reservoir of distilled or rain water. 'boilwater.

The vessel containing water must have a small neck, or be fitted with a cover so that the air inside the screen may not be moistened by evaporation from the vessel. The wet bulb should be at least 3 inches to leeward of the dry bulb in the prevailing wind; usually, however, it is placed to the right of the dry bulb thermometer in the screen.

The muslin covering on the wet bulb thermometer should be kept trimmed and changed before it becomes dirty; it should be stretched smoothly over the bulb and tied by looping two strands of the cotton used for supplying moisture in a clove hitch. The cotton thread must be kept free from grease, and as straight as possible, as sagging of the cotton will cause water to drip from the sag and the reservoir will rapidly become empty. The cotton wick must be changed when the muslin is changed. The wet bulb temperature should be read before mounting fresh muslin or more than 15 minutes afterwards, to allow the temperature indicated to be the equilibrium temperature.

Evaporation from the wet covering of the bulb causes cooling, which, in turn, causes the wet bulb temperature to be lower than that of the dry bulb, unless the atmosphere is "saturated," when no evaporation will take place from the muslin, and no cooling will result, thus the two thermometers should read the same temperature.

If the wet bulb reading is above that of the dry bulb—

(a) Wipe any moisture off the dry bulb which might be acting as a wet bulb;

(b) Repeat readings at two minute intervals because the dry bulb might be falling more rapidly than the wet whose temperature might be lagging, and so reading too high.

Readings of the wet bulb over 80° F. should be regarded with suspicion, and readings over 90° F. are practically impossible.

In frost, the wet bulb must be coated with a thin layer of ice from which evaporation takes place as from water. It may be necessary in these circumstances to wet the muslin slightly with ice cold water by means of a camel hair brush, 10-15 minutes before observing the temperatures, which should not be recorded until the wet bulb reading has fallen below that of the dry bulb **and remains steady.**

6. The Maximum Thermometer

This thermometer consists of a mercury-in-glass thermometer with a constriction in the bore about 1 inch from the bulb. The thermometer is slung nearly horizontally with the bulb slightly lower than the other end. When the temperature rises, the mercury expands past the constriction; but when the temperature subsequently falls and the mercury contracts, the thread breaks at the constriction, so that its upper end remains in position to register the highest temperature recorded. The time at which the maximum temperature was attained may be taken from the trace of a thermograph.

The maximum thermometer should be set daily at 0900 hours. This is done by swinging it briskly through an arc, the bulb being held away from the observer, and the thermometer being kept in the shade. After setting, the reading should be the same as that of the dry bulb thermometer.

The maximum reading may be—

(a) too low due to wear in the constriction of the bore—this can be checked by heating the bulb with the fingers; the column should not fall on removal of fingers;

(b) too high because of the mercury slipping forward after the thermometer is replaced after setting.

The latter defect may be remedied by altering the inclination at which the instrument hangs.

7. **The Minimum Thermometer**

This thermometer consists of a spirit thermometer carrying a small index in the stem, and is slung like a maximum thermometer. As the temperature falls the index is carried towards the bulb by the spirit; but if the spirit expands in a subsequent rise of temperature it flows past the index which is left in position to indicate the lowest temperature reached.

The minimum thermometer is usually set at 1500 hours when the reading should be that of the dry bulb thermometer. The time at which the minimum temperature was reached can be taken from the trace of the thermograph.

Especially in hot climates spirit thermometers should be examined to detect the presence of bubbles in the stem or bulb, or of drops of liquid in the upper part of the stem, or in the small bulb at its end. These defects can be remedied by holding the thermometer with the bulb down and the tube vertical, and jolting the bulb end against a soft pad. Subsequently the thermometer should be held vertically for some hours to allow any liquid which may have been left on the walls of the tube to drain down to the main column.

8. **Terrestrial and Solar Radiation Thermometers**

These instruments are described on pages 35, 36 A.O.H.

9. **Diurnal Variations of Temperature**

Except at the poles there is, normally, a daily rise and fall of temperature which is much **greater over the land than over the sea.** Normally the maximum temperature is reached about 1400 hours local mean time and the minimum at about sunrise. Especially in winter, the normal time of maximum temperature may be advanced at many coastal stations by sea breezes which, springing up in the afternoon, bring in relatively cool air, causing a sudden drop in temperature. **Clouds,** intercepting the incoming and outgoing radiation, **tend to smooth out the diurnal variation,** keeping the temperature low by day and comparatively high by night; clear weather enhances the diurnal variation.

B. OBSERVATION OF HUMIDITY

10. **Psychrometer**

A combination of dry and wet bulb thermometers suitably mounted is called a "psychrometer" and can be used, with the help of suitable tables, to determine relative humidity, dew point, pressure of aqueous vapour, etc. The amount by which the temperature of the wet bulb is reduced below that of the dry bulb thermometer is found to depend on the ventilation to which the instruments are exposed, as well as on the amount of water vapour present in the atmosphere. The aspirated and whirling types of psychrometers ensure exposing the thermometers to a strong current of air; a wind of 3 m.p.h. is assumed to pass the thermo-

meters mounted in a Stevenson Screen. The table employed to determine relative humidity, etc., from the dry and wet bulb readings must be calculated for the particular wind speed to which the thermometers are exposed.

11. **Hygrograph**

The Hair Hygrograph (described on pages 74-76 A.O.H.) is an autographic instrument for recording relative humidity. It depends upon the fact that a length of human hair freed from fat varies with relative humidity, increasing in length as the humidity increases. The instrument is exposed in a Stevenson Screen. In addition to making available the relative humidity at any time it also serves to indicate the changes of relative humidity which take place.

12. **Absolute and Specific Humidity**

Other measures of humidity which are of value for various purposes are:—

(a) **"Absolute Humidity,"** which expresses the moisture con-content of the atmosphere as the mass of aqueous vapour (in grams) contained in a given **volume** of air (in cubic metres). Absolute humidity is proportional to the pressure of aqueous vapour in the air **at a given temperature.**

(b) **"Specific Humidity"** is a measure of the **mass** of aqueous vapour (in grams) contained in a given **mass** of **moist** air (Kgm.). It is unaffected by changes in the temperature or pressure of the air as long as aqueous vapour is not added or subtracted by evaporation or condensation.

$$\text{Specific humidity} = 622 \frac{e}{p} \text{ gms./kgm., where}$$

e = pressure of aqueous vapour pressure.

p = atmospheric pressure.

It may be obtained approximately as $e \times 20{\cdot}94$, where e is aqueous vapour pressure in inches.

(c) **"Relative Humidity"** is the ratio between the actual quantity of water vapour present in the air and the quantity of water vapour required to saturate the air at the same temperature.

13. **Diurnal Variation of Humidity**

At island and coastal stations the variation of "absolute humidity" follows that of temperature very closely; in winter the maximum occurs in early afternoon and the minimum shortly after sunrise; in summer there are maxima about 0900 and 2100 hours local time and minima at about 1500 hours and shortly after sunrise.

The variation of "relative humidity" depends upon that of "absolute humidity" but is controlled mainly by the variation of temperature; the variation is reversed with the maximum occurring at sunrise and the minimum in early afternoon.

14. **Examples**

Determination of Relative Humidity and "Dew Point" Vapour Pressure based on readings of dry and wet bulb thermometers exposed in a Stevenson Screen with a draught less than 1·5 metres per second and using Tables V and VI, pages 132-147, A.O.H.

1. Dry Bulb 76° F. Wet Bulb 70° F. (p. 141).
   Relative Humidity = 73%. Vapour Pressure = 0·651 ins.
   Dew Point = 66·6° F.
2. Dry Bulb 91·5° F. Wet Bulb 66° F. (p. 138).
   Relative Humidity = 20%. Vapour Pressure = 0·296 ins.
   Dew Point = 44·8° F.
3. Dry Bulb 49·4° F. Wet Bulb 41·7° F. (page 145).
   Relative Humidity = 46%. Vapour Pressure = 0·162 ins.
   Dew Point = 29·5° F.
4. Dry Bulb 44·6° F. Wet Bulb 37·8° F. (p. 146).
   Relative Humidity = 47%. Vapour Pressure = 0·138 ins.
   Dew Point = 25·5° F.
5. Dry Bulb 63·6° F. Wet Bulb 57·7° F. (p. 143).
   Relative Humidity = 67%. Vapour Pressure = 0·398 ins.
   Dew Point = 52·7° F.

References: Australian Observers' Handbook (A.O.H.).

SECTION 7

OBSERVATION OF ATMOSPHERIC PRESSURE

1. THE MERCURY BAROMETER

A barometer is an instrument for measuring the pressure of the atmosphere. The simplest type consists of a glass tube about 36 inches long, closed at one end, filled with mercury, and inverted so that its lower end dips into a metal cistern also containing mercury which is open to the atmosphere. The pressure of the atmosphere can be determined by the pressure exerted by the column of mercury which it supports. The type in general use within the Commonwealth Meteorological Service is the Kew Pattern Land Station type, as described in lectures on "Instrumental Meteorology" (Section 4).

The pressure at the foot of the mercury column is equal to the weight of mercury supported on unit area of cross-section. The weight of the mercury in addition to being proportional to the length of the column is dependent upon firstly, its density, and secondly, the attraction of gravity. In turn the density depends upon the temperature of the mercury and the attraction of gravity depends upon the distance of the barometer from the centre of the earth. Thus, the height of the column supported by a particular pressure of the atmosphere will depend upon the temperature of the mercury and the latitude of the station.

2. UNITS OF ATMOSPHERIC PRESSURE

In meteorology the basic unit of pressure is the **"bar,"** equal to a pressure of 1,000,000 dynes per sq. cm. representing approximately the pressure of "one atmosphere" (about 15 lbs. per square inch). In practice atmospheric pressures are expressed in millibars (= 1000 dynes per sq. cm.).

When lying flat, one half-penny exerts a pressure of about 1·1 mbs. The average pressure of the atmosphere (about 30 "inches" of mercury or 1016 mbs) is approximately the same as that exerted at the base of a column of 930 half-pennies.

Normally, in temperate and high latitudes pressure varies between 970 and 1030 mbs., but readings as high as 1050 mbs. and as low as 925 mbs. may occur very occasionally. The highest and lowest pressures (reduced to mean sea level) on record are respectively 1072·2 mbs. at Irkutsh (Siberia) and 886·8 mbs. on board a ship 400 miles east of Luzon (Philippines).

Owing to the fact that it is the height of a mercury column which is actually measured, it is convenient to express atmospheric pressure as determined by a mercury barometer in units of **length,** i.e., inches. All that is necessary is to specify the temperature of the mercury and the value of gravity. The standard values of these quantities that were selected are:—

Temperature of mercury = 32° F.
Density = 13·5955 gm. per cub. cm.
Value of gravity = that at M.S.L. in latitude 45°
(= 980·617 cm. per second per second).

Under these conditions the weight of a cubic cm. of mercury under standard conditions of temperature and gravity is 13332·0 dynes and the following numerical relations have been accepted:

1 "inch" of mercury = 33863·2 dynes per sq. cm.
= 33·8632 mbs.

and conversely—

1 millibar = 0·0295306 "ins." of mercury.
1 bar = 29·5306 "ins." of mercury.

Corrections have to be applied to observations taken under conditions other than standard.

3. THE SCALE ON A KEW PATTERN BAROMETER

In this type of instrument the scale is fixed in position so that it yields a direct indication by means of a single setting on the summit of the column of mercury.

However, as the level of the mercury in the tube changes, the level of the mercury in the cistern will also change, and, as a result, the zero of the scale will not coincide with the level of the mercury in the cistern.

If the cistern and the glass tube are cylindrical, the change in the level of the mercury in the cistern corresponding to a given change in pressure is a definite fraction of the change of level of the top of the mercury column at a particular temperature, the value of this fraction depends only on the dimensions of the instrument.

In order to compensate for this "capacity effect" the scale of the instrument is contracted. In practice, a nominal inch of the scale on a Kew pattern barometer is either 0·96 or 0·98 inch.

The "inch" scale on a Kew pattern barometer is graduated from below 26 to over 32 inches in 20ths of inches. Moving against this scale is a vernier divided into 25 divisions and equal in length to 24 main scale divisions. As each vernier division is 1/25th of a scale division (1/20th in.) short of a scale division the vernier reads to—

$$\frac{1}{25} \times \frac{1}{20} = 0{\cdot}002 \text{ inch.}$$

The first vernier division is marked 0, and every fifth one numbered consecutively 1, 2, 3, 4, and the last one is 5.

In order to determine the length of the mercury column indicated by the scale of the instrument, the vernier is moved until the lower edge of the vernier, and also the lower edge of the sliding piece at the back of the tube, which moves with it, appear in the same straight line, and are just touching the uppermost part of the meniscus of the mercury. A little light will then be visible under the vernier at each side of the apparent point of contact. The object of the sliding piece at the back of the instrument is to avoid errors of parallax by assuring that the observer's eye is at the same level as the top of the mercury. Read main scale to the graduation just **below** the zero line on the vernier, look at the vernier scale and find the graduation coinciding with a main scale division, and determine the fraction represented, and add it to the main scale reading.

Sometimes it will be found that two vernier divisions are nearly in coincidence with two scale divisions, but that neither of them is in exact coincidence. In these cases, the vernier can be taken to read to ·001 inch.

The vernier measures fractions only up to ·050 inch. On the main scale the 1/20th (·050) divisions are marked as halves of the 1/10th (·100) divisions. Thus, it is necessary to check whether the scale division is a 1/10th or a 1/20th division, before adding on the fraction represented by the vernier reading.

The millibar scale is graduated in millibars from 880 to 1100 mbs., every 10th division being numbered. The vernier, equal in length to 39 scale divisions, is divided into 10 vernier divisions, so that each vernier division is equal to 3·9 scale divisions, and is thus 0·1 scale division short of 4 scale divisions. The vernier thus reads to 0·1 mbs. altitude

4. THE EFFECT OF THE HEIGHT OF THE INSTRUMENT

One of the first characteristics of the mercury barometer illustrated by Torricelli in 1643 was the fact that, as a barometer is lifted, the level of the mercury falls. The depression is about 1/10th inch for a rise of 90 feet, or 1 mb. for a rise of 30 feet. This variation of pressure with ~~latitude~~ is large compared with the normal horizontal variation of altitude and masks the horizontal pressure variation.

Thus, as forecasting depends largely upon a comparison of the air pressure at a large number of stations of varying altitudes, it becomes necessary to adjust the pressure of each station so that it represents the pressure that would be exerted if the station were lowered to a common datum level. "Mean Sea Level" has been adopted as the common level and the process is called the "reduction of pressure to mean sea level."

In order to reduce barometric pressure to M.S.L. there must be added to it the pressure due to a column of air extending vertically from barometer level down to sea level. Such a column of air has, of course, no real existence. It would be provided by a vertical wind shaft sunk to sea level from the station. The correction depends upon the length of such an air column (i.e., upon the altitude of the station) and upon the density of the air in the column. The effects of temperature and humidity are much less than the length of the column. The effect of humidity is, in practice, neglected and a value is assumed for the mean temperature. The M.S.L. pressure may be obtained by means of the formula—

$$\log_{10} p_0 = \log_{10} p + \frac{h}{221T}$$

where p_0 = pressure at M.S.L., p = pressure at a station level, h = altitude of station in feet, and T = mean absolute temperature of the air column between station level and M.S.L.

For a station not more than 1000 feet above sea level, T in the formula may be taken as the temperature of the station itself. For a station at a higher altitude than 1000 feet this method may involve considerable errors. If at such a station the temperature is abnormally high, the correction term $h/221T$ is too small; resulting in a value of M.S.L. pressure which is too low. Similarly, if the temperature is abnormally low, the corrected pressure is too high.

The method of reducing high level barometric pressures is called the "plateau reduction" and is not yet satisfactory. The difficulty arises because of the large percentage of the total sea level pressure which must be added to the station pressure—the correction may be as large as 5 inches. Any error involved in determining the temperature of the hypothetical air column between the station and sea level will cause a very large error in the sea level pressure.

5. TEMPERATURE EFFECTS

Firstly, it must be pointed out that as the brass scale is graduated at a temperature of 62° F., and the standard temperature for mercury is 32° F., the pressure indicated on a Kew pattern barometer can never be correct and a correction for temperature must always be made.

As the Kew barometer may be considered as a closed reservoir partly of iron (the cistern) and partly of glass (the tube) allowance must also be made for the unequal coefficients of expansion of glass and iron.

The necessary corrections are made by means of tables calculated after making assumptions which are justifiable in practice. It is necessary, however, to determine the temperature of the

instrument (on the attached thermometer) and the temperature of the air (in a Stevenson Screen) as accurately as possible.

A change of 1° F. in the temperature of the normal barometric column corresponds to a change of 0·003 in. in its height. Thus, the measurement of the temperature of a primary standard barometer requires the most refined methods. If it is desired to limit the errors to ·0001 in. the temperature must be measured to 0·02° C. which may be regarded as very near the limiting accuracy attained under favourable conditions by high precision mercury thermometers.

6. GRAVITY EFFECTS

The attraction of gravity varies with both latitude and height.

At mean sea level the value of "g" for any latitude, θ, **can** be obtained from the formula—

$$g_\theta = g_{45}\ (1 - 0{\cdot}00259 \text{ Cos } 2\theta)$$

which is the basis of the corrections for reducing barometer readings to standard gravity in latitude 45°, as set out in Table VIII, p. 151 of A.O.H. AUST OBSERVERS HANDBOOK

The variation of "g" with height is given by the formula—

$$g_h = g_o\ (1 - 0{\cdot}0000000\ 597\ h)$$

where g_h represents the acceleration due to gravity at a height "h" feet above mean sea level. For stations below an altitude of 1000 feet, this effect may be neglected in "reducing" barometer readings to M.S.L. In the case of high stations, however, the correction becomes important. The magnitude of the correction can be seen from the table—the correction being always **subtracted.**

GRAVITY CORRECTION FOR ALTITUDE

Height feet	Reading of Barometer 25in.	26in.	27in.	28in.	29in.	30in.
Surface ..			0·000	0·000	0·000	0·000
500 ..			0·001	0·001	0·001	0·001
1000 ..			0·002	0·002	0·002	0·002
1500 ..		0·002	0·002	0·003	0·003	0·003
2000 ..		0·003	0·003	0·003	0·003	0·004
2500 ..		0·004	0·004	0·004	0·004	
3000 ..		0·005	0·005	0·005	0·005	
3500 ..		0·005	0·006	0·006		
5000 ..	0·007	0·008	0·008			

7. WIND EFFECT

A barometer is usually mounted in a room, and a wind blowing past doors or windows will often cause the pressure in the room to be different from that of the atmosphere outside. Strong wind may have quite a marked effect on the reading of a barometer in a building; the pressure may be greater or less than the static pressure outside, depending upon the position of the barometer in regard to windows, doors, etc.

The order of this error may amount to 1 mb. for a wind of 30 m.p.h., and to 12 mb. for wind velocity of 100 m.p.h.

A similar effect is noticed at stations at the foot of cliffs or marked topographical features, with certain wind directions.

No allowance can be made for this, however.

8. THE CORRECTIONS TO BE MADE

The first correction to be applied is that to determine the true length of the mercury column **at the particular temperature.** This correction, called the "Index Correction," is supplied after comparison of the instrument with a primary standard by N.P.L. or some other recognised authority. It corrects all the "residual errors" remaining after corrections for temperature have been made, and includes the correction for capillary depression. It appears that the index correction slowly alters with time, and barometers should be subjected to periodical tests. When a barometer is first installed considerable time must be allowed for the instrument to "settle" before the "index correction" may be correctly applied.

The corrections which have to be then applied to the length of the column of mercury as read on the scale are due to:—

(a) Variation in the temperature of the scale from the standard temperature 62° F. at which it is graduated.

(b) Variations of pressure exerted by mercury column due to—

- (i) variation of temperature of mercury from 32° F.;
- (ii) variation of gravity from that at M.S.L. in latitude 45°.

(c) Height of the barometer above M.S.L. which will involve the determination of the extra pressure which would be exerted if the air column stretched downwards to M.S.L.

The Determination of the Corrections

1. **Temperature Correction to Kew Pattern Barometers.**—The correction for the variation of the temperature of the barometer from the standard temperatures for the scale and the mercury is based on a formula from which a table has been prepared,

making this correction easy. The table is printed on page 150 of the A.O.H. No interpolation is required between the vertical columns but it is required between the horizontal temperature lines.

2. **Correction to Standard Gravity in Latitude 45°** is obtained by reference to a table calculated from the relation given in para. 6. This will be found on page 151 of the A.O.H.

After corrections have been made for—

(a) index error;
(b) temperature variation;
(c) variations in gravity;

the corrected value is called **"Station Level Pressure."**

3. **Reduction of "Station Level Pressure" to "Mean Sea Level,"** i.e., obtaining weight of the fictitious air column between the cistern of the barometer and M.S.L. This is obtained from tables printed on pages 152-155 of the A.O.H.

Example

Pressure as read = 29·982 inches.
Attached Thermometer (A.T.) = 62° F.
Dry Bulb = 59° F. latitude 34°; height = 365 feet.
Correction for "index" error = — ·014 inch.

Pressure as read	=	29·982	inches
Index error	=	—·014	
		29·968	
Temperature Correction	=	—·091	(page 150)
		29·877	
Gravity Correction	=	—·029	(page 151)
Station Level Pressure	=	29·848	
Reduction to Mean Sea Level (height = 365′; D.B. = 59)	=	+·398	(page 154)
		30·246	
M.S.L. pressure	=	30·246	inches

On a particular station, the reduction to mean sea level is facilitated by means of a "Correction Card." By incorporating the constant values of index error, gravity correction, etc., the reduction is effected in two steps (or three steps in the case of high level stations).

The Barometer Correction Card for Canberra Aerodrome is given below:—

BAROMETER CORRECTION CARD

CANBERRA AERODROME (A.C.T.) 35° 20′ S., 149° 15′ E., 1850 feet.

Index Error Correction:	.. ..	+0·017
Gravity Correction: Height	.. ..	—0·003
Latitude	..	—0·024
		—0·027
Standard Barometer	.. ..	28·1″

TABLE A

(See page 150, Australian Observer's Handbook)

TABLE B		TABLE C					
Bar. Reading after Corr. by Table A (inches)	Correction (inches)	Dry Bulb	ADD	Dry Bulb	ADD	Dry Bulb	ADD
		°F.		°F.		°F.	
27·1	−0·070	34	2·032	58	1·934	82	1·846
·2	·063	35	2·027	59	1·930	83	1·843
·3	·056	36	2·023	60	1·926	84	1·839
·4	·049	37	2·019	61	1·922	85	1·836
·5	·042	38	2·016	62	1·918	86	1·832
·6	−0·035	39	2·012	63	1·914	87	1·828
·7	·028	40	2·008	64	1·910	88	1·824
·8	·021	41	2·003	65	1·906	89	1·820
·9	·014	42	1·999	66	1·903	90	1·816
28·0	·007	43	1·994	67	1·900	91	1·813
·1	0·000	44	1·990	68	1·896	92	1·810
·2	+·007	45	1·985	69	1·893	93	1·806
·3	·014	46	1·981	70	1·890	94	1·803
·4	·021	47	1·977	71	1·886	95	1·800
·5	·028	48	1·973	72	1·882	96	1·797
·6	+0·035	49	1·969	73	1·878	97	1·793
·7	·042	50	1·965	74	1·874	98	1·790
·8	·049	51	1·961	75	1·870	99	1·786
·9	·056	52	1·957	76	1·867	100	1·783
29·0	·063	53	1·954	77	1·863	101	1·780
·1	+0·070	54	1·950	78	1·860	102	1·777
		55	1·946	79	1·856	103	1·775
		56	1·942	80	1·853	104	1·772
		57	1·938	81	1·850	105	1·769

To use:—Read attached thermometer and barometer. Obtain correction for attached thermometer from the A.O.H. Apply Table B correction and then correction from Table C. This gives Mean Sea Level Pressure. At no stage is Station Level Pressure obtained. An example of the use of the table is:—

Barometer Reading	28·216″	Barometer as read	28·216″
		Table A	— 0·057″
Attached Thermometer	51·3°		28·159″
Dry Bulb	38·7°	Table B (using 28·159″)	+ 0·004″
			28·163″

Corrected Reading	30·176″	Table C	+ 2·013″
		Fully Corrected	30·176″

9. PRESSURE INFORMATION IN WEATHER REPORTS TO AIRCRAFT

Weather reports to aircraft contain pressure at **aerodrome level** obtained from the barometer reading by making a single correction obtained from a table such as that prepared at Essendon and reproduced below:—

TABLE FOR OBTAINING PRESSURE AT AERODROME LEVEL

Station: ESSENDON

Barometer Number: 1442 **Index Correction:** — ·004
Latitude: 37° 48′ S **Correction for Gravity:** — ·019
Barometer Cistern: 3 ft. higher / . . . . ft lower } than centre of landing area **Corrections:** + ·003

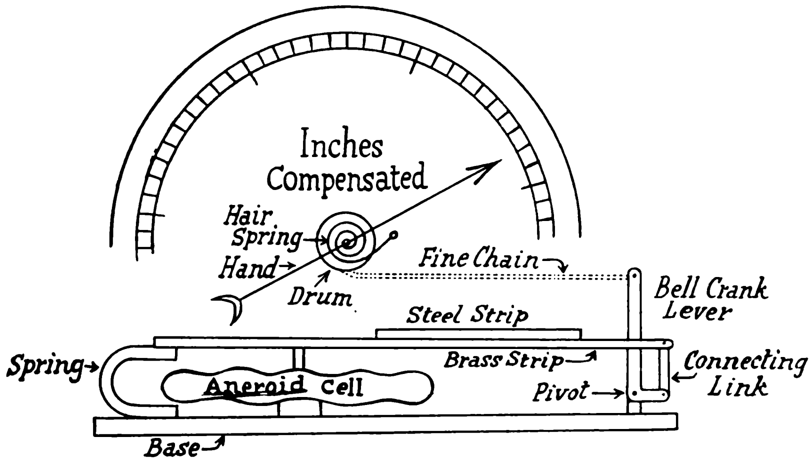
Corrections to be applied to Uncorrected Reading of Barometer

Attached Thermo-meter	Correction (inches)	Attached Thermo-meter	Correction (inches)	Attached Thermo-meter	Correction (inches)
35	—·034	60	—·105	85	—·176
36	·037	61	·108	86	·178
37	·040	62	·111	87	·181
38	·043	63	·113	88	·184
39	·045	64	·116	89	·187
40	·048	65	·119	90	·190
41	·051	66	·122	91	·193
42	·053	67	·125	92	·196
43	·057	68	·128	93	·198
44	·060	69	·131	94	·201
45	·063	70	·133	95	·204
46	·065	71	·136	96	·206
47	·068	72	·139	97	·209
48	·071	73	·141	98	·213
49	·073	74	·145	99	·215
50	·076	75	·148	100	·218
51	·080	76	·150		
52	·083	77	·153		
53	·085	78	·156		
54	·088	79	·159		
55	·091	80	·161		
56	·093	81	·164		
57	·096	82	·168		
58	·099	83	·170		
59	·103	84	·173		

10. USE OF AN ANEROID BAROMETER

Changes in atmospheric pressure can be measured by the effect of changes in atmospheric pressure on an "aneroid" cell. It must be calibrated by comparison with a corrected mercurial barometer.

An aneroid barometer consists of an "aneroid" cell and a system of levers which transmit any changes in the aneroid cell to a pointer which moves across a dial.



A good aneroid barometer is compensated for temperature and the only error to be considered is an index error which may occur after the original calibration. This error is due to hysterisis in the metal of the cell.

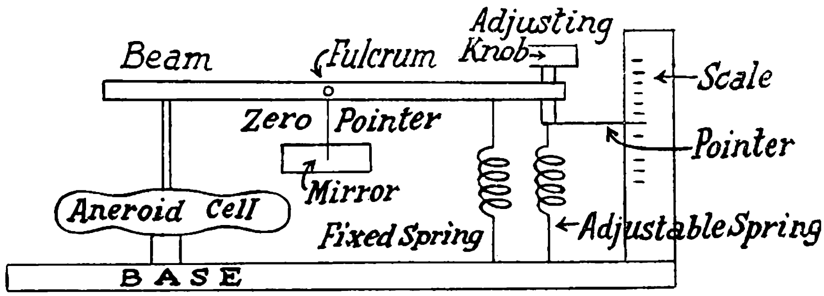
If the pressure changes rapidly there is a lag in the recording of the change and two defects are evidenced:—(1) Lag—due to the "stiffness" of the metal in the cell; (2) Hysterisis—the total pressure change is not immediately shown by the aneroid, but only a certain fraction of it and the remaining fraction is shown eventually as the cell adapts itself to the new condition. Actually both of these errors are due to the metal of which the cell is constructed and research has been conducted to find the most suitable metal for the construction of the cell.

An aneroid barometer can be made recording by replacing the points with a pen arm which gives a trace on a special chart. Such an instrument is called a barograph.

A barograph enables the pressure tendency to be seen at a glance from the nature of the trace. The change in pressure over a given period (usually three hours) may be found by reading the pressure indicated by the pen point and then going back the required time and reading the pressure as indicated by the trace.

The time interval should always be worked back from the pen as the time indicated on the chart may not be the correct time, especially with weekly clocks.

One type of aneroid—the Paulin—is constructed so that the aneroid cell is always in the same configuration and any change in atmospheric pressure is balanced against an adjustable spring. The pressure is indicated by a pointer attached to the adjustment of the balancing spring.



Diagrammatic Representation of Paulin.

This instrument is claimed to be without lag or hysterisis owing to the cell always being at the same configuration after being set.

All aneroid barometers should be set at station level pressure and set according to the readings obtained from a corrected mercury barometer. As correction to sea level depends upon air temperature, an aneroid set to read mean sea level pressure, at a station above sea level, will only give the correct mean sea level pressure at the particular temperature prevailing at the time at which it was set. An aneroid barometer may be used as an altimeter. Usually the scale is graduated in heights instead of pressures, but in some altimeters there are two scales—(1) a pressure scale, which is fixed, (2) an altitude scale, which is movable. The latter scale is set to read the height of the station above mean sea level and then when the aneroid is moved it will show the height of its new position.

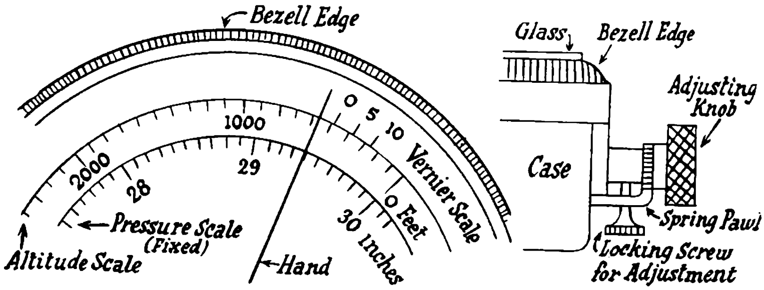
The accuracy of the altimeter depends upon (a) the horizontal pressure gradient, (b) the movement of the isobaric system.

(a) If the altimeter is used at any appreciable distance from the station at which it was set, allowance must be made for the horizontal pressure gradient.

(b) Allowance must be made for the change of the isobaric system if any appreciable time elapses between the time of setting and use.

The Short and Mason "Surveying Aneroid" has a fixed pressure scale, an altitude scale which may be moved by a knurled knob on the case and a vernier scale which may be used to read heights to an accuracy of 1 foot, up to 6000 feet.

It is constructed so that 10 vernier divisions are equal to 21 main scale divisions. To use this place the zero of the vernier immediately under the pointer by moving the bezell edge and using the magnifying glass (avoid parallax). Then look to the right along the vernier until a division on it coincides with a division on the whole scale, the number of this division is added to the main scale reading.



The small figures on the scale are 100's of feet and each division on the main scale is 10 feet. The knurled knob which moves the main altitude scale is locked by a small set screw and a catch which must be released before any adjustment can be made and locked again afterwards. The Kollsman Altimeter is a special form of aneroid which has a fixed scale and the aneroid assembly is rotated by the setting knob.

This instrument is set in either of two ways:—

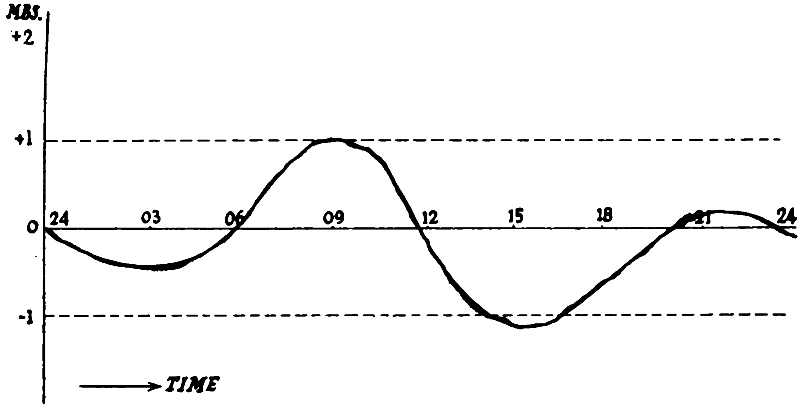
(1) On the ground set either to zero or to the height of the 'drome above sea level.

(2) In the air, set either (a) sea level Kollsman number in the window then height above mean sea level will be shown on dial. (b) Station level Kollsman number in the window, when height above station will be shown on dial.

11. DIURNAL VARIATION OF PRESSURE

The characteristic feature of the diurnal variation of atmospheric pressure is a 12-hourly oscillation which has its maxima at the same local time all over the inter-tropical and temperate zones. The amplitudes of these waves are greatest at the equator and diminish towards the poles. The amplitude varies with place approximately as the cube of the cosine of the latitude. It is greatest on equinoxes and least on solstices, is greater on clear days than cloudy, and is greater over land than over sea. This

double wave of pressure may be seen occurring with great regularity each day on the traces from a barograph in the tropics, the maxima occurring approximately at 10 h. and 22 h. and the minima at 4 h. and 16 h. The nature of the change can be seen from a graph showing 3-hourly changes in M.S.L. pressure at Melbourne for the month of May:—



The curve indicates the slow pressure change about 0900 hours, which is one of the reasons why observations made at that time are selected as the main basis of forecasting and analysis throughout the day.

SECTION 8

MEASUREMENT OF UPPER WINDS: USE OF THE PILOT BALLOON THEODOLITE

The measurement of direction and speed of winds in the upper atmosphere is of primary importance to aviation. It is performed by observations of the movement of a "pilot balloon" with a special theodolite. The pilot balloon is filled with hydrogen, so that its buoyancy causes it to rise at a predetermined ascensional velocity.

The balloon is inflated by means of a special "filler." The required amount of hydrogen is determined as that necessary to hold the balloon, together with a mass, known as the "free lift" **balanced** in air.

The **"free lift"** is the propelling force which causes the balloon to rise. It is defined as the mass which **together with the dead weight of the balloon** (including the mass of a "tail" or lantern which may be subsequently attached) is necessary to balance the total lift of the hydrogen. When it is released, the balloon ascends with a constant velocity which is related to the "free lift." It can be shown that, for the sizes of balloons most commonly used, the velocity can be calculated from the formula—

$$V = q \frac{L^{\frac{1}{2}}}{(L + W)^{\frac{1}{3}}}$$

where q is a constant determined experimentally, L is the "free lift" and W is the "dead weight" of the balloon itself. For balloons of diameter up to 48 inches, $q = 84$, so that if the weight of the balloon is 30 grams—

- a "free lift" of 19 grams will cause it to rise at 100 metres/min.
- a "free lift" of 36 grams will cause it to rise at 125 metres/min.
- a "free lift" of 68 grams will cause it to rise at 150 metres/min.

For large balloons a different formula must be used. (See Instrumental Section 8.)

The care of hydrogen cylinders and the method of filling the balloon are dealt with in "Instrumental Meteorology," Section 8.

THE USE OF THE PILOT BALLOON THEODOLITE

Notes on the description, care and maintenance of the Watts Pilot Balloon Theodolite are given in the course on "Instrumental Meteorology."

(a) **Mounting the Theodolite**

Set up the tripod firmly on the ground. Remove the cap screwed on the threads of the tripod head. The theodolite should now be carefully removed from its box, transported to the tripod (without jarring) and screwed on the head.

The tangent screw mechanisms should be disengaged, so that both the horizontal and vertical movements of the telescope mounting are free to turn. The telescope mounting should then be held with the left hand, while the tribrach and sub-base are turned with the right hand until the sub-base is screwed home on the head of the tripod or pillar.

It will be found easier to **turn the instrument initially in the direction of unscrewing until the threads have engaged, and then to screw up until the theodolite is securely held. Avoid the use of excessive force in screwing up or the threads may be damaged.**

Remove the cap of the object glass and place it in the box, which should now be closed. By means of the tripod legs, bring the instrument to a convenient height, with its base approximately level.

(b) **Focusing the Eye-Piece**

Shades are provided for solar observations or for protection from glare. If a shade is necessary, the extension tube should be fitted on the end of the telescope and the shade placed in it. **Ensure that the tangent screw mechanisms are disengaged,** so that the telescope can be freely rotated. **Direct the telescope towards the sky** or a sheet of white paper, so that the field of view is illuminated, and then re-engage the tangent screws. Rotate the eye-piece (which is screw focusing) until the **graticule divisions** are seen distinctly on the field of view. On some types of theodolites, the eye-piece and graticule may also be focussed on an object together as one unit. When using an instrument of this type, direct the telescope to a distant object and adjust the eye-piece until the object is distinct in the field of view. If now the telescope is directed to a distant balloon, both the object and the graticule divisions should be sharply defined in the field of view, and there should be **no relative motion of the two** (parallax) when the observer's head is moved slightly from left to right.

Notice the two-fold object—

(a) To obtain clear image of graticule scale;

(b) To detect errors of parallax due to displacement of graticule scale from the focal plane of the objective.

(c) **Levelling the Theodolite**

Ensure that the horizontal circle tangent screw is disengaged. The instrument should first be levelled approximately by moving the legs of the tripod until the bubble level on the sub-base is

centred in its circle. In the first position—with the bubble level parallel to the line of the two travelling screws—the levelling should be adjusted **by turning both levelling screws simultaneously.** The screws should be held with the thumb and forefinger of the right and left hands, respectively, and should be turned so that **both forefingers** are moved towards the level or **both** away from the level—the bubble will move in the direction of movement of the forefinger of the **right** hand. These motions ensure that neither of the levelling screws is screwed hard home into its socket. Before continuing the levelling in the second position—with the bubble level at right angles to its original position—the observer should move to the **right** and continue the adjustment by using the forefinger and thumb of the **right hand only.** Once again, the bubble will move in the direction of the forefinger of the **right hand.** If the theodolite is slowly rotated in azimuth through 360° the bubble should remain in the centre of the level throughout the rotation. If, **after several repetitions** of the above procedure, the bubble still shifts appreciably, a test should be made of the **accuracy of adjustment of the "bubble level."**

If the tripod is moved after levelling has been performed it will be necessary, of course, for the levelling to be repeated.

(d) **Orientation of Horizontal Scale**

Select as orientation mark some distant object of which the true bearing is known, say A°. Add 180° to this bearing giving, say, B°. Lock the horizontal circle and disengage the horizontal tangent screw, swing the theodolite until horizontal circle reads B°. Engage the horizontal tangent screw and set this reading accurately with the vernier. Now unlock the horizontal circle and swing theodolite until the rough sights are in line with the orientation object. Lock the horizontal circle and accurately set the theodolite to the reference object by means of its slow motion adjusting screw. The theodolite is now oriented and, when the tangent screw is disengaged, is ready for use.

(e) **"Following the Balloon"**

Having prepared the theodolite and the balloon, the **stop watch is started as the balloon is released.** (NOTE: If a clockwork buzzer is used, the balloon should be released at the **end** of a signal.) A piece of bent wire attached to the frame of the theodolite will hold a watch in a suitable position. It has been found convenient to hold a pencil in one hand and a piece of stiff paper in the other, for the purpose of recording the azimuth and elevation angles, without unduly affecting the easy manipulation of the verniers actuating the tangent screws. **Readings are made at minute intervals, the azimuth is read first,** the **elevation second** and **both angles are read to the nearest decimal place.** Some theodolites'have the vernier drums graduated in minutes (60 minutes = 1 degree) and a rapid mental division by six to convert minutes into decimals of a degree will enable the reading to be entered without loss of time.

Angles should be read and entered rapidly, otherwise the balloon may pass out of the field and often be completely lost. **Should the azimuth be changing rapidly, read it alone at the time of observation,** return the eye quickly to the eye-piece and bring the baloon back towards the centre of the field (without altering its elevation), then read the elevation, and although conditions may remain difficult, it is almost always possible to jot the readings down within the minute.

Again, **should the balloon be moving rapidly through the field,** release the azimuth or elevation tangent screw, or both, and follow the balloon by a smooth motion, guiding the telescope through changing elevation with the right hand and controlling azimuthal change with the left.

It is better to maintain view of the balloon and by doing so miss a reading or two, than to endeavour to take a reading when an obvious risk of losing the balloon entirely exists.

Because of rapid changes of azimuth when the balloon is near the zenith, it may be necessary to release **both** tangent screws and to turn the telescope by hand. Confusion is sometimes caused in these cases by the observer overlooking the fact that the horizontal and vertical graticule lines apparently change places.

It should be the endeavour of observers to follow the balloon without strain, the eye may be rested from time to time (all flights are not difficult) while some prefer to keep the idle eye open. It is helpful also to occasionally look at the balloon over the rough sights with the naked eye.

Balloons are followed until lost to view for one of several reasons. Sometimes when the flight promises to be a long one, it is necessary to abandon it in order to have the pilot report available at the scheduled time. Considering the altitudes at which aeroplanes now fly, observers should endeavour to gain information concerning winds up to a height of 12,000 feet or approximately 4 kilometres; while for subsequent study of synoptic situations additional value is given the records if they are available up to 16,000 feet, the height to which temperature and humidity records made daily at some few stations extend.

(f) **Obtaining True Bearings of Reference Points**

The theodolite may be accurately oriented by taking a "sight" on the sun at **local apparent noon** (when it is due north of the meridian). Having determined the time of local apparent noon and levelled the theodolite, proceed as follows:—

(i) Set the pointer on 360° on the azimuth scale and engage the azimuth circle tangent screw, thus locking the observation axis (i.e., the axis about which the theodolite swings when observing the balloon).

(ii) Free the orientation axis and then swing the theodolite. (The reading on the azimuth scale must remain at 360°.)

(iii) Direct the telescope at the sun, using a **proper solar filter,** or if this is not available, by obtaining an image of the sun on a white card held behind the eye-piece.

(SEE SPECIAL INSTRUCTIONS IN PARA. VIII.)

(N.B.: DO NOT ATTEMPT TO VIEW THE SUN WITH THE EYE.)

The telescope should be continually moved, so that the image of the sun remains near the centre of the field of view.

(iv) At the instant of local apparent noon ensure that the sun is centred in the theodolite telescope by the slow motion adjusting screw after the horizontal circle has been clamped. The telescope will then be set on a true **bearing** of 360° as shown on the azimuth scale.

(v) Keeping the orientation axis locked, now release the azimuth tanget screw and direct the telescope on to a permanent object suitable for use as a reference point. Carefully direct the telescope on to the reference point and read the bearing shown on the azimuth scale. A careful note must be made immediately of a description of the reference point and its true bearing from the position. If necessary, a stake or peg can be hammered into the ground for use as a temporary reference point. A number of suitable reference points at various distances and in different directions should be selected, and their true bearings determined.

(vi) The theodolite may now be oriented at this position at any subsequent time. The reading of the reference point is obtained by adding or subtracting 180° to or from its true bearing and clamping the azimuth scale so that this reading is obtained when the telescope is directed at the reference point.

(vii) Within or near the tropics, difficulty may be experienced when the sun at noon is in the vicinity of the zenith. **The sun's path in the heavens is symmetrical about local apparent noon,** so having found as before the corresponding standard time, **observe the sun at equal intervals of time before and after it crosses the meridian.** Thus, two azimuths will be obtained, and the **bisection of the angle between them will give the true north-south direction.**

Example

At Cooktown (long. 145° 17′ E.) on December 1st.

Sun crosses meridian at 12.02½ p.m.

When sun centred at 10.02½ a.m. azimuth is, say, 79·8°.

When sun centred at 2.02½ p.m. azimuth is say, 143·6°.

Bisecting the angle between these readings, we get 111·7° as the azimuth giving due south since sun is to the south of the station.

(viii) If no solar screen is available use this method:—

1. Mount and level theodolite.
2. Set azimuth at 360·0°.
3. Loosen orientation locking screw and free elevation tangent screw but keep azimuth tangent screw engaged.
4. Set telescope at an angle of elevation of about 45° and rotate theodolite on its orientation axis until the shadow of the front sight lies along the telescope.
5. Keeping azimuth steady, elevate telescope until the shadow of tip of front sight falls on rear sight.
6. Hold a piece of paper about 6 inches away from the eye-piece so that an illuminated disc is seen upon it, then adjust focus of graticule until an image of graticule is seen on the paper.
7. Lock orientation clamp.
8. Keep image of sun on centre of image of graticule, using elevation tangent screw and orientation vernier screw. **(DO NOT TOUCH AZIMUTH TANGENT SCREW.)**

At the instant of local apparent noon the telescope will be pointing true north.

9. Take sight on to reference object and make a note of its true bearing as described previously.

SECTION 9

PRINCIPLES OF PILOT BALLOON CALCULATIONS: GRAPHICAL METHODS

The pilot balloon is so light in comparison with its size that it may be considered to adjust itself almost immediately to the direction and speed of the air in which it is floating at any particular instant. If the position of the balloon can be determined relative to the earth's surface, at successive intervals of time, it is then possible to calculate the horizontal speed at which it is moving and so obtain the wind speed and direction.

Before the movement of the balloon over the surface of the earth can be traced it is necessary to determine its vertical height at the time of each observation. The following methods of obtaining the height are in common use:—

(1) By assuming a constant rate of ascent;

(2) by observation of the angle subtended at the point of observation by a tail of known length hanging below the balloon; and

(3) by measuring the distance of the balloon from the point of observation with a range-finder.

The height being known at the end of each minute the horizontal distance of the balloon from the observer is found from the elevation reading and its horizontal position can be determined from the azimuth.

ASSUMED RATE OF ASCENT

This method is convenient because of its simplicity and is reliable on occasions when the atmosphere is stable (especially at night) and vertical currents are small. The rate of ascent of a balloon is governed by the free lift which is the force driving the balloon upwards, and the resistance to its motion imposed by the air. If L grams be free lift of a balloon, W grams the weight of the rubber balloon and any equipment attached to it, and v the rate of ascent, it can be shown that for balloons up to 100 inches circumference, metres/min. v is given by the formula—

$$V = \frac{84\,L^{\frac{1}{2}}}{(L + W)^{\frac{1}{3}}}$$

While it is desirable to know the weight of the balloon and to adjust the free lift as accurately as possible, some degree of tolerance is permissible for—

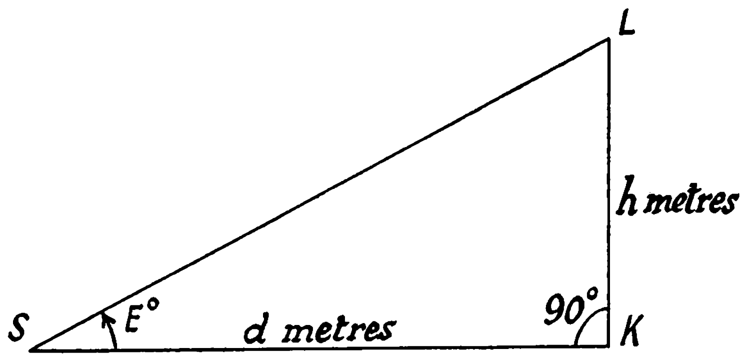
(1) a variation of 4% in the free lift produces a change of 1% in the rate of ascent;

(2) a variation of 12% in the weight of the balloon alters the rate of ascent by only 1%;

(3) a deviation of the balloon at any instant of 5% of its assumed height will not be serious practically.

DETERMINATION OF THE HORIZONTAL DISTANCE OF THE BALLOON FROM THE STATION

If, at any instant, the height h metres and the elevation E° are known, the horizontal distance d metres of the balloon from the station is easily found by projection on to the horizontal plane of the station—



$$\text{Here } \frac{d}{h} = \frac{SK}{KL} = \cot E.$$

and $d = h \cot E$ metres.

Further, if after some interval of time, the height and elevation of the balloon are H metres and E°, its horizontal distance will be

$$D = H \cot E \text{ metres.}$$

As these distances will generally be measured in different directions, one **cannot** be subtracted from the other **arithmetically;** but the horizontal displacement of the balloon in the interval of time is the vector difference between H cot E and h cot E.

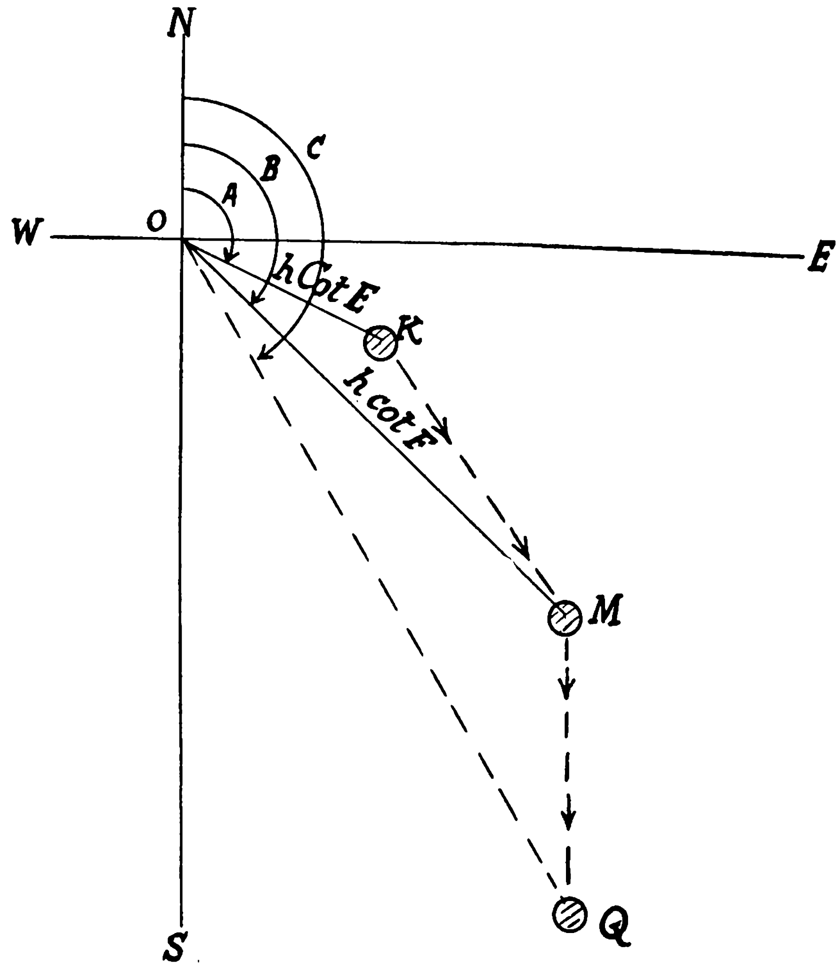
In practice, the height and elevation of the balloon are determined at the end of one minute intervals. Thus, the horizontal displacement between successive positions of the balloon represents the mean **velocity of the wind in metres per minute.** The mean velocity over any interval of time is found by dividing the horizontal displacement in that interval by the number of minutes between the observations.

If it is desired to measure the velocity in units of metres per second the horizontal displacement must be divided by 60; if it is desired in units of kilometres per hour, the horizontal displace-

ment must be multiplied by 0·06. It is usual to divide by 60 at the time of calculating h cot E, so that values of

$$\frac{h \cot E}{60}$$

are obtained; the vector differences between these values at the end of successive minutes then give the velocity of the wind in metres/sec. The velocity in km./hour is obtained by multiplying by 3·6 or by using a special scale.



DETERMINATION OF VELOCITIES

Determination of the horizontal displacement between the position of the balloon at the successive times of observation gives a measure of the velocity of the wind and its direction.

Suppose that at the end of the first minute the balloon at height h has elevation E° and azimuth A°, and that at the end of the second minute the balloon at height H has elevation F° and azimuth B°. As before the horizontal distances from O the point of observation will be h cot E and H cot F respectively.

Because the direction of the wind is specified according to the direction **from** which it is blowing the azimuth readings of the balloon are actually equal to its **bearing plus 180°.** This is effected when orienting the theodolite, and no further allowance for this is necessitated.

If OK and OM are the directions corresponding to the azimuth angles A and B, the positions of the balloon (projected on to a horizontal plane) will be O,K,M at the moment of release and at the end of the first and second minutes of its flight respectively.

During the first minute the balloon moved from O to K so that its mean velocity and direction of movement during that minute are represented in magnitude and direction by the line OK.

During the second minute the balloon has moved from K to M so that its mean velocity and direction of movement during this interval are represented in magnitude and direction by the line KM.

If during the third minute the azimuth reading changes to C°, and the position of the balloon to Q, the balloon will have moved from M to Q and the mean velocity and direction during the minute will be represented by the line MQ. The process can be repeated for any number of readings taken over any period of time.

Thus, in order to determine the mean velocity of the wind in the layers through which the balloon rises in the first, second, third minutes, it is necessary to obtain the velocities and directions represented by the lines OK, KM, MQ, etc. This may be done graphically by direct measurement, or mathematically by resolving the distances of the balloon from the point of observation into west-east and south-north components, subtracting those corresponding to one position from those corresponding to the next and compounding the differences.

THE GRAPHICAL METHOD OF CALCULATION

Fundamentally the graphical method for the calculation of upper wind velocities from observations of a pilot balloon flight consists of plotting the horizontal distances of the balloon from the point of observation. Some means of determining h cot E having been provided, the distance is plotted in the direction of the azimuth reading.

The mean velocities of the wind as indicated by the horizontal displacements in the one minute intervals can then be read off the graph with the aid of an appropriate scale and a protractor.

THE PILOT BALLOON CIRCULAR CALCULATOR

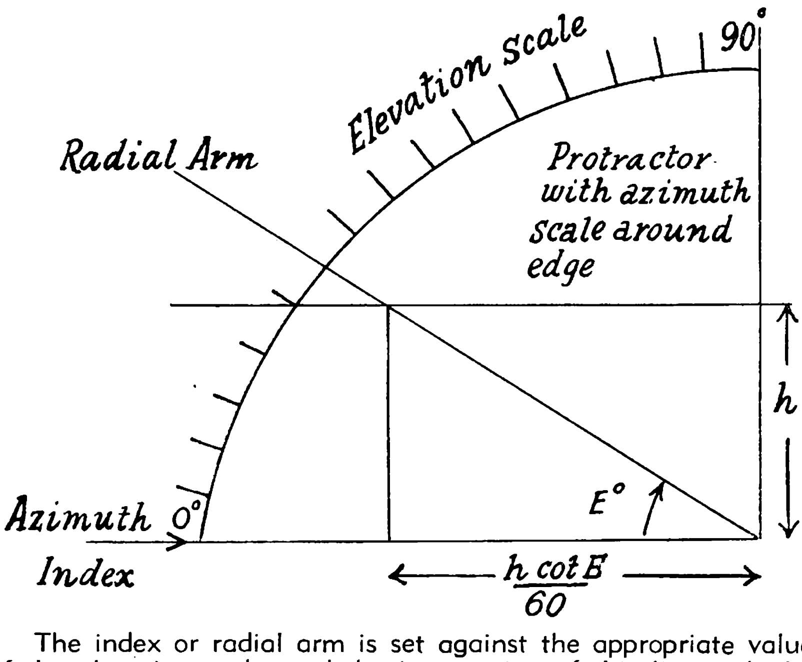
This device consists of a protractor, 8 inch radius, mounted so that it rotates on top of a squared chart. The path of the balloon is conveniently plotted on the protractor whose surface is etched so that pencil lines can be drawn on it.

The azimuth reading of the balloon is plotted by turning the protractor until the given value is set opposite the index line on the chart underneath.

When working with assumed rates of ascent (150 metres per minute) values of—

$$\frac{h \cot E}{60}$$

are obtained directly by solving a right-angled triangle graphically. A radial arm mounted concentrically with the protractor swings over a subsidiary scale for the angles of elevation and a series of straight lines representing the heights of the balloon. The elevation scale and the height lines are drawn on the underneath chart to the appropriate scale.



The index or radial arm is set against the appropriate value of the elevation scale, and the intersection of this line with the horizontal line representing the height of the balloon is projected vertically downwards on to the index line for the azimuth scale.

The scale is so arranged that the values of h cot E are divided by 60 automatically.

In this way the position of the balloon at each minute is quickly plotted. If these points are joined by straight lines the projection of the path of the balloon on a horizontal plane is obtained.

The **direction** of the mean wind speed during each minute is obtained by turning the protractor until the straight line representing the movement of the balloon in each particular minute is parallel to the horizontal lines of the chart and reading the angle against the azimuth index.

The mean velocity of the wind during each minute is measured by placing an appropriate scale (1 cm. = 5 metres/sec. = 18 km. per hour = 11·2 miles per hour) against the line representing the movement of the balloon during each particular minute.

The values of the mean velocity and the direction of the wind in the layers through which the balloon rises in the various minute intervals, are recorded on a special form.

The following hints will be found helpful:—

1. See that grid is fastened securely and is taut.

2. See that protractor is central with respect to the grid and has as little slackness as possible on its mounting pin.

3. Keep protractor clean.

4. Use a sharp pencil so that the plotted points will be as small as possible; ring each point and number it.

5. Avoid parallax by keeping the eye vertically above the position of the point.

6. Always check a flight before erasing it.

7. Remember that a change of scale necessitates a mental calculation to get the correct velocity, and also the point at which the scale is changed must be plotted twice—once at each scale.

8. The table gives the necessary factor for possible scales of plotting and time intervals between readings. The velocity may also be obtained by multiplying the measured velocity by the reciprocal of the scale and dividing by the number of minutes.

Scale	Period of Reading	Factor
FULL	1 MINUTE	1
FULL	2 MINUTE	$\frac{1}{2}$
FULL	4 MINUTE	$\frac{1}{4}$
HALF	1 MINUTE	2
HALF	2 MINUTE	1
HALF	4 MINUTE	$\frac{1}{2}$
QUARTER	1 MINUTE	4
QUARTER	2 MINUTE	2
QUARTER	4 MINUTE	1

9. To obtain the mean wind of a **number** of layers—

(a) Join the point representing the bottom of the layer to that representing the top of the layer.

(b) Divide this line into the same number of parts as the number of minutes taken by the balloon to traverse the layer.

(c) The mean direction is obtained by turning the protractor until this line is parallel to the index line and reading the azimuth.

(d) The mean velocity is obtained by measuring the distance from the point representing the bottom of the layer to the first dividing point.

SECTION 10

PHYSICAL PROCESSES OF CLOUD FORMATION

(See R.A.A.F. Manual 153—Section VIII—Pages 59-63.)

SECTION 11

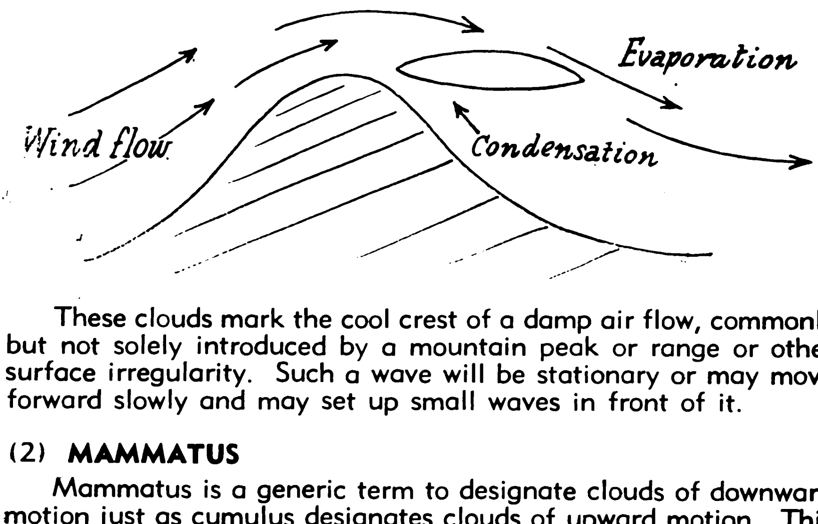
SUB-TYPES AND SPECIAL VARIETIES OF CLOUDS

In addition to the clouds included in the International Classification, there are commonly occurring varieties of clouds of an important physical nature. They include:—

(1) LENTICULAR CLOUDS

Clouds of an ovoid, lens, or airship shape with clean-cut edges, existing at all levels from Cs. to St. They most commonly occur with alto-cumulus. It is only occasionally that a perfect typical form is seen; more often several cloud banks are joined together into an irregular mass. The lenticular shape is not difficult to recognize, even in heavy banks or sheets of the cloud. The lenticular cloud grows from the windward edge by condensation due to dynamic cooling and thins towards the leeward by progressive evaporation due to dynamic warming. It is therefore thickest in the middle and thins to nothing at the sides.

The cloud is formed by a large mass of clustered cloudlets and is apparently disposed horizontally. The cloud is usually of smooth appearance.

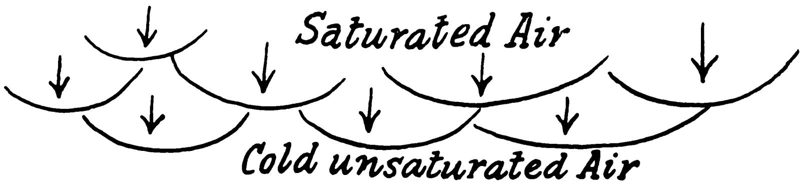


These clouds mark the cool crest of a damp air flow, commonly but not solely introduced by a mountain peak or range or other surface irregularity. Such a wave will be stationary or may move forward slowly and may set up small waves in front of it.

(2) MAMMATUS

Mammatus is a generic term to designate clouds of downward motion just as cumulus designates clouds of upward motion. This description is given to all clouds whose lower surfaces form protuberances, pockets or festoons as rounded masses hanging downwards. It may occur on the undersurface of (i) the spreading top sheet of cumulo-nimbus and remnants of "false cirrus," (ii) stratus or alto-stratus, and (iii) strato-cumulus or cumulus. It is

commonly called mammato-cumulus and is essentially a reversed cumulus, caused by downward currents producing a sag or pendulous bulge in the cloud face, thus forming its festooned appearance.



Saturated air warming at s.a.l.r and becoming colder than unsaturated air warming at d.a.l.r.

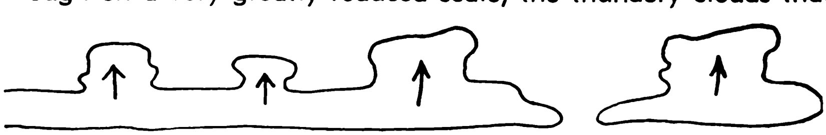
Each bulge persists for some time, appearing gradually and dissipating gradually. This cloud form appears to be found in circumstances where a column of air, formed of saturated air overlying colder unsaturated air, sinks as a whole. The upper saturated air warms at the saturated adiabatic lapse rate and thus becomes colder than the unsaturated air warming at the dry adiabatic lapse rate. If the sinking is slow the descent of the cloud particles will not be accompanied by evaporation rapid enough to destroy the outline of the pouches. The colder air into which the cloud particles are descending must not have too low a relative humidity since otherwise the evaporation would be too rapid. These limiting conditions account for the fact that mammatus formations usually are observed only for short periods. Precipitation seldom falls from mammatus itself because of the evaporation involved—it indicates, however, conditions favourable for early precipitation.

Mammatus may be formed in such a variety of ways that a simple record of the fact of its occurrence will tell but little concerning the atmospheric processes involved. If it is formed from a cumulo-nimbus, precipitation will usually begin when the main body of the cloud comes overhead.

In Australia it has been established that mammato-cumulus is not associated with the type of alto-stratus in which severe ice accretion occurs.

(3) CASTELLATUS

This description is applied to a rare but very important variety of alto-cumulus, sometimes called the "turret cloud" met with in thundery weather in summer. The cloudlets are developed more in the vertical direction than in the horizontal and closely simulate, though on a very greatly reduced scale, the thundery clouds that

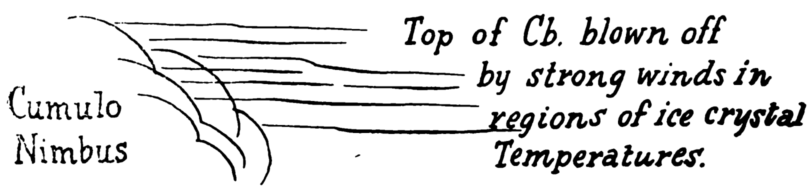


frequently follow their appearance. Unstable conditions are frequently associated with their production, which can be taken as an indication of rapidly rising currents of warm air at a very high level and on a small scale.

(4) FALSE CIRRUS u

This cloud is known as "false" cirrus on acount of its resemblance to true cirrus. It is not found at the same level, but it does not appear to differ in actual construction from the normal type. The highest thunder heads of a Cb. may reach into a stratum of air of much greater velocity in which the topmost variations of the cloud are drawn into long radiating wispy bands and fibres of snow or ice crystals—truly cirrus cloud.

A skilled observer may frequently be able to notice several small differences between the appearance of the high, true cirrus, and of the lower, false type. The latter is usually denser or more solid in its appearance; the fibres are not so sharp and clear but somewhat more woolly in their appearance. The colour of the cloud is frequently cream instead of the pure white of high cirrus, and the cloud is scattered more irregularly over the sky. The banded structure and long radiating lines which are so characteristic of true cirrus are seldom seen in false cirrus.



(5) FRACTO-NIMBUS OR SCUD

This is a low detached cloud fragment, too thin and fog-like to produce rain, that occasionally is seen drifting rapidly beneath heavy nimbo-stratus at an average elevation of probably not more than 1000 feet. The term is applied if a layer of nimbo-stratus separates up in a strong wind into shreds or if small loose clouds are visible and floating underneath a large nimbo-stratus.

(6) RADIATUS

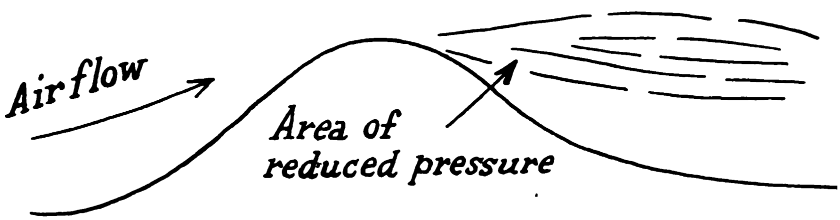
This description is applied to cloud formations arranged in long parallel bands which seem to proceed from one particular point on one horizon and to converge again towards another point diametrically opposite the first one. It can be applied particularly to cirrus when the bands sometimes consist of a multitude of the very finest of thread-like fibres which, singly, would be almost invisible but which when grouped together add a somewhat hazy appearance to the whole band. These are called "polar" bands.

(7) UNDULATUS

This term is applied to elongated elements parallel and arranged like sea waves. When applied to Sc. it generally describes roll-cumulus.

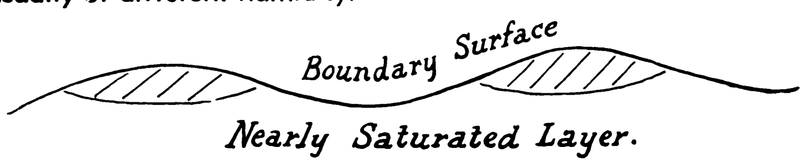
(8) THE BANNER CLOUD

This cloud resembles a large white flag floating from a mountain peak in strong winds. The pressure to the immediate leeward of such peak is more or less reduced. The resulting low temperature intensified by the mountain surface, appears to cause a cloud which though continuously evaporating, as consistently reforms. The cloud is frequently lenticular.



(9) BILLOW CLOUD

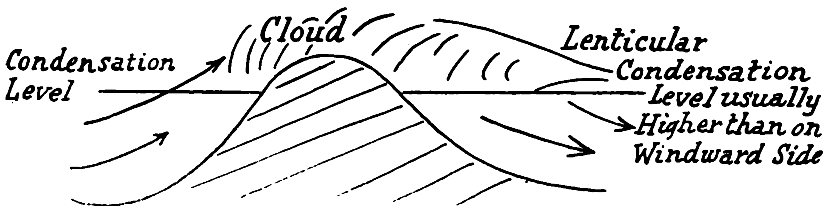
Billow clouds, also called "wave" clouds, occur in series of approximately regularly spaced bands, generally with intervening strips of blue sky. They usually form in the lower cirrus region at an elevation of 20,000 to 26,000 feet but may occur at any level from the surface. They are caused by the flow of one air stratum over another of different temperature and density, and usually of different humidity.



When two strata of air of different densities or vapour content flow over each other, billows of great wave length and often of large amplitude are generated in the same manner, as winds produce ocean billows. As the series of waves progress the atmosphere involved rises and falls and is therefore subjected to alternate dynamical heating and cooling with the maxima and minima temperatures corresponding in the troughs and crests respectively. Hence when the under layer is wholly or nearly saturated, the wave crests are cloudy and the troughs clear. Even though the billow cloud appears to consist continuously of the same mass, nevertheless it is rapidly evaporating on the rear or descending portion of the wave and as speedily forming on the front or ascending portion.

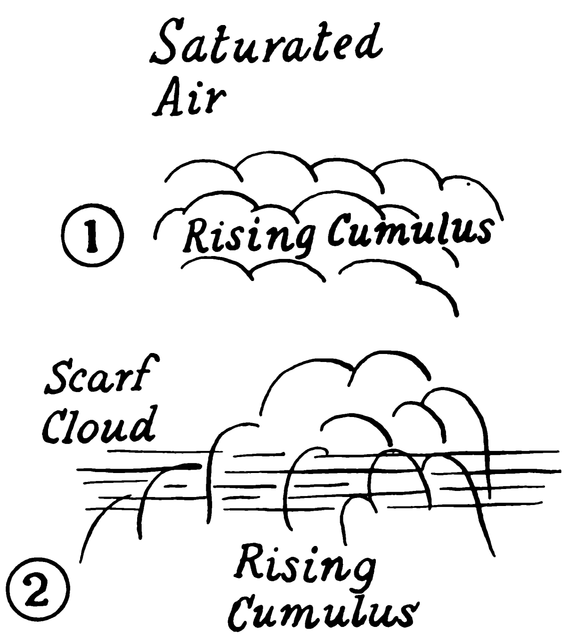
(10) **CREST CLOUD**

This cloud is formed by the upward deflection of the wind by a long mountain ridge. It usually covers the higher slopes as well as the top. If it only develops along the upper ridges of the deflected winds it forms a lenticular cloud above and to the leeward of the mountain ridge. It remains as long as the supply of moisture to condense as cloud is maintained by the wind. Examples are found on the windward side of Queensland coastal ranges.



(11) **FUNNEL OR TORNADO CLOUD**

Formed at the end of a waterspout or tornado, the tornado cloud is a funnel-shaped extension of generally, if not always cumulo-nimbus. It is produced by expansional cooling incident to the rapid rotation of the atmosphere in which it appears.



(12) **SCARF CLOUD**

It sometimes happens that as a cloud rises rapidly and to great heights, a thin cirrus-like cloud converging upwards forms above

the topmost billow and at first is entirely detached from it. Then as the convection progresses the flossy cloud becomes more extensive and rests on the thunder head. A little later it mantles the shoulders, the heads being free, and may even drape the sides of the towering cumulus. In all stages it resembles a great silken scarf.

It is caused by the lifting and consequent expansion and cooling of the air immediately and to some distance above a rising mass of cumulus. Generally this expansion of the super-incumbent atmosphere produces no visible effect. Occasionally, however, there exists a thin stratum of nearly saturated air which, when lifted by the rising cumulus, develops a local cirrus-like cloud. If the saturated layer is thin, as it often is, the cumulus head may rise quite above it into drier air, leaving the filmy cloud at practically its original level.

(13) SQUALL CLOUD

A long dense cigar-shaped cloud rotating on a horizontal axis. Usually formed at a height of about 2000 feet, it advances ahead of a line squall.

These squall clouds are often seen in association with the "Southerly Busters" of the New South Wales coastal areas. They are usually preceded by calm conditions and immediately preceded by strong winds and dust and then, as the squall cloud passes overhead, the wind direction changes and rain may follow. The temperature will always fall rapidly after the passage of a squall cloud associated with a passage of a front, but if with an isolated cumulo-nimbus cloud there need not be a temperature change.

SECTION 12

CODE SPECIFICATIONS FOR CLOUDS

The following key may be helpful in determining the code numbers to use. The first step is to consider the state of the sky as a whole and determine whether the clouds are at lower, middle or upper levels. The observer should then analyse the individual clouds, and if clouds at more than one level are present he should determine which clouds belong to each of the three principal levels. He will then determine the code numbers to use in each case, bearing in mind the necessity of following the evolution of the sky.

UPPER CLOUDS

Code No.	Cloud Types			
$C_H = 4$	Delicate and increasing usually with hooks ending in a point or in a small tuft—increases in amount in time and in a certain direction—often occurs on the front of a typical disturbance. If this Ci. tends to pas~~s into Cs. It should be~~ coded as $C_H =$ 5 or 6.		Increasing	Detached, or in groups or patches
$C_H = 3$	More or less dense—probably derived from Anvil.			
$C_H = 1$	Ci.—~~scarce~~—delicate, not increasing, scattered and isolated masses. Ci. with upturned hooks or tufts must not be included in this type.	Delicate	Stable or decreasing	
$C_H = 2$	Ci.—abundant—same as 1 but more abundant over whole sky and without any tendency to increase in any particular direction.			
$C_H = 3$	Probably derived from Anvil of Cb.—sometimes shows virga in places. Occurs either in rear of typical disturbances or else around thunderstorms.	Dense		
$C_H = 5$	Sheets of Cs. or of fibrous Ci. merging into Cs. especially towards horizon—often in polar bands. Occurs in front of typical depression.	Below 45°	Increasing	Layer or sheet covering all or part of the sky
$C_H = 6$	Ci. (often in polar bands) or Cs. advancing over the sky. Found in the front part of a typical disturbance a little nearer the centre than $C_H = 5$.	Above 45°		
$C_H = 7$	Cs.—has recently extended over the whole sky.			
$C_H = 7$	Veil of Cs. covering the whole sky. (a) Thin, very uniform nebulous veil, sometimes hardly visible, sometimes relatively dense—always without definite detail (halo). (b) A white fibrous sheet with more or less clearly defined fibres.		Stable	
$C_H = 8$	Cs.—not increasing and not covering whole sky. The case of a veil or sheet of Cs. reaching the horizon in one direction but leaving a segment of blue sky in the other direction—the segment of blue sky does not get smaller. The edge of sheet is clear cut.			
$C_H = 9$	Cc. predominates. Occurs on front or lateral edges of a weak disturbance. If the Ci. fibres or sheet of Cs. merely becomes slightly corrugated in parts the Cc. is neglected. If the Ci. or Cs. degenerates wholly into Cc. it is coded as $C_H = 9$.			

MIDDLE CLOUDS

Code No.	Cloud Types			
$C_M = 6$	Formed from the spreading out of the tops of Cu. clouds of sufficiently great vertical development—may undergo an extension of their summits while their bases may gradually melt away. These sheets of Ac. are generally fairly thick and opaque at first with rather large elements, dark and soft; later they may thin out and finally have rifts in them. May be seen in the rear of disturbances, after squalls or showers.	Spreading or advancing over the sky		In groups, patches or layer with openings
$C_M = 5$	Ac. in parallel bands or an ordered layer advancing over the sky—occurs on the lateral side of disturbances — distinguished from Cm. = 3 by the progressive deterioration of the sky and by the irregular thickness of the layer.			
$C_M = 8$	Ac. Castellatus. Occurs (a) as a series of small cumuliform masses with more or less vertical development, arranged in lines and resting on a common horizontal base; (b) as scattered tufts, white or grey, but without definite shadows, with rounded parts very slightly domed.	With Cumuliform tufts		
$C_M = 4$	Ac. in small isolated patches—individual clouds often showing signs of evaporation and being more or less lenticular in shape—shows irisations, lens shaped, fairly thick with little or no shadows. Generally scattered over the sky, and often at different levels—mostly in constant charge. Higher and more delicate than Cm. = 6 and different structure from Cm. = 5. On extreme lateral side of disturbances.	Stable or evaporating		
$C_M = 3$	Ac. in single layer—sheet at one level only. Fairly regular, of uniform thickness. The cloudlets are separated by clear skies or lighter gaps and neither very large nor very dark. Layer is fairly stable.			
$C_M = 1$	Typical thin As.	Thin	Lowering or thickening	Continuous layer or sheet
$C_M = 2$	As. (thick), Ns. or Nb. No definite relief on under surface and often accompanied by underlying low, ragged and dark clouds (Cl. = 6—FC, FN, FS).	Thick		
$C_M = 7$	Ac. or Ac. associated with As, with definite relief on under surface. (a) As. may lie above sheets of Ac. (b) Ac. with a grey veil of cloud lying at a level very little lower. (c) When Ac. grows thicker and cloudlets fuse together. (d) When As. or Ns. changes progressively into Ac. or Sc. . . (e) Opaque cloud sheets with a more or less irregular corrugated structure but comparatively thick.	Degenerating Thick		
$C_M = 9$	Ac. in the typical chaotic, thundery type of sky. It is very complex and patches of middle cloud, more or less fragmentary are seen superimposed. There are all the transitional forms between low Ac. and the fibrous veil. The sky is covered with different layers. Generally there is not a continous sheet—blue patches may be seen.			

LOWER CLOUDS

Code No.	Cloud Types			
$C_L = 1$	**Small, with slight vertical development (typical** fair weather Cu.). Fracto Cu. (Cl. = 1) of fine weather must be distinguished from FC ($C_L = 6$ or $C_L = 9$) of bad weather. $C_L = 1$—detached white clouds usually in a blue sky and remain detached. $C_L = 6$—They form under a grey sheet of As. or Ns. and are dark, receive little light and generally become numerous. $C_L = 9$—They form under the bases of Cb. or very large Cu. clouds or in the spaces between them.	With Vertical Development		Detached Masses
$C_L = 2$	Cu.—heavy and swelling, without anvil top—active vertical growth without fibrous summit—sometimes towering masses—sometimes of complex heaps with cauliflower form.			
$C_L = 3$	Cb.—Great vertical growth with fibrous summit.			
$C_L = 4$	Sc. formed from spreading out of Cu.— (a) Cu. tops may settle down and the bases may spread out. (b) Bases may melt away and the tops may spread out.	Without Vertical Development		
$C_L = 6$	FN, FS or FC under As. or Ns.		Low bad weather clouds	
$C_L = 9$	Under Cb.			
$C_L = 5$	Single layer of St. or Sc.—fairl, regular and not very dark or menacing. The Sc. has often semi-transparent parts, or even clear spaces between the elements of the clouds. If the Sc. is clearly high up (about 6500 ft.) and related to Ac. it is coded as Cm = 3.			Sheet or Layer
$C_L = 6$	Low clouds of bad weather (FN, FS or FC) may be broken or may ultimately fuse into a continuous sheet, but through interstices the veil of relatively light, higher cloud may be seen. This type is found in the middle of a typical disturbance.			
$C_L = 7$	Sc. with fair weather Cu. below, i.e., Cu. forming below an already existing sheet of Sc. which they do not penetrate.			
$C_L = 8$	Sc. with towering Cu. below or with Cu. or Cb. penetrating the layer.			
$C_L = 9$	Cb. covering the sky with ragged low clouds of bad weather below.			

For further specifications and illustrations, see "Codes for Cloud Forms and States of the Sky" (U.S.W.B. 1938).

SECTION 13

STATES OF THE SKY

(See R.A.A·F. Manual 153, pages 64-75)

SECTION 14

CLOUDS ASSOCIATED WITH WARM AND COLD FRONTS

(See R.A.A.F. Manual 153, pages 145-147)

SECTION 15

THE PILOT BALLOON SLIDE RULE

1. The Pilot Balloon Slide Rule is different from an ordinary slide rule inasmuch as it was designed for a special purpose and has scales arranged accordingly.

Fixed Scales

(i) On the top fixed scale there are two sets of sine and cosine scales, one from 0·5° to 90° and the other from 10° to 90° (for sines). The sines of angles from 70° to 90° are arranged on an arc to spread the graduations and make them readable. The longer scale (0·05° to 90°) is called the Azimuth scale and will be referred to as scale A. The sine and cosine scale on the right is used with rangefinder ascents and will be referred to as scale E.

(ii) The lower fixed scale has two scales—both marked "Elevation," but the main one, from 3° to 84·3°, is a tangent scale, and the shorter scale, from 0° to 63°, is a secant^2 scale and is used for calculation of heights by "tail flights." This lower fixed scale will be referred to as scale D.

Sliding Scale

This has two scales, one continuous logarithmic scale on the top of the scale, which will be called scale B. If the mark on the extreme left is taken to be unity, then the following units marked 10 will be 10, 100, and 1000, respectively. Notice also the divisions between 1 and 2; care is needed in assigning the correct value to readings on this section of the rule.

Most of the scale on the lower edge of the slide is identical with the upper scale, but on the left end will be noticed a part which is marked "Graticule." This scale is used in conjunction with the secant^2 scale for finding the height of a balloon when a tail of known length (a multiple of 12 metres) is attached to the balloon and the apparent length of the tail measured by the number of P.B. theodolite graticule divisions covered by the tail.

Notice that this scale increases from **RIGHT** to **LEFT** and is marked from 16 to 16.

The whole of the lower scale of the slide is referred to as scale C.

Four cursors are provided with the rule to facilitate setting the observed readings and obtaining the required components. None is shown on the sketch of the rule to avoid confusion. They

are made to slide in grooves machined in the two outer edges of the rule. A small blade spring keeps them in position and ensures that they are "square." A line etched on the surface of the glass is used as a setting line.

2. SUBSIDIARY MARKINGS

When using a slide rule, several marks are used which are not engraved on the rule by the makers.

(a) It is convenient to keep the numerical values as small as possible, and as an aid in this direction the value of the horizontal displacement is divided by 60. If the time interval between observation is in minutes, the new value of the horizontal displacement will represent the horizontal displacement of the balloon in 1 second, the actual units depending upon whether the assumed rate of ascent is in feet or metres.

The actual division by 60 is done by fixing a division mark on the slide rule as follows:—Move the slide of the rule until the figure 6 on scale C falls on elevation of 45° on scale D, then, with a pencil, place a mark on the upper fixed scale, between scales A and E to coincide with figure 10 on scale B.

Any number now placed in coincidence with 45° on the tangent scale (scale D) or in coincidence with the 90° end of the arc of scale A will be divided by 60 at the mark just made (called mark H), the decimal place being fixed by inspection (see para. 15).

Examples

(i) 24 placed on scale B to coincide with the 90° end of arc on scale A gives 0·4 on mark H.

(ii) 36 on scale B coinciding with 90° end of arc on scale A reads 0·6 on mark H.

(iii) 1230 on scale B coinciding with 90° end of arc on scale A reads 20·5 on mark H.

(b) As the components are calculated in metres per second and a result in ~~kilometres per hour~~ is required, a reference mark is necessary on the rule for their conversion.

Place 10 on scale B opposite the 90° end of arc of scale A and look to the right along scale B until 3·6 is found; this point on scale B will coincide with 21·1° on the sine scale of scale E and a pencil line should be drawn at this point. The final velocity of the wind in kilometres per hour will be read at this line which will be referred to as line V. Examples of use of this will be found later in these notes.

(c) Sometimes the wind velocity is required in miles per hour, and this may be read from a line fixed in the following manner:—Set 10 on scale B to coincide with the 90° end of arc on scale A. Look to the right along scale B until 22·4 is found and make a pencil mark M on scale E to correspond with it; the line will be 12·9° on sine section of scale E.

Example

Convert 7 metres/sec. to miles per hour.

Place 7 on scale B to coincide with end of arc on scale A and read off 15·7 m.p.h. ct mark M.

(d) When using a rangefinder, another mark is necessary to convert the range found in yards into metres. The obtain this mark, set 10 on scale C in coincidence with 45° on scale D, and then looking to the right along scale C, find 109 (it will be just to the right of the end of scale D), and make a pencil mark to correspond with this reading on scale D; this will be referred to as mark R.

For marks R and M, a cursor may be set if it is not desired to put a mark on the rule, but care must be taken to prevent accidental movement of the cursor during working.

Some calculators use a mark for obtaining the code figure for the wind velocity at the same time as the final velocity, the position of this is given later in para. 9.

3. CALCULATION OF DISPLACEMENT

By assuming a constant rate of ascent for a pilot balloon, the mean velocity and direction of the travel of the upper winds can be found at any required height. The usual rate of ascent is 150 metres per minute.

The readings of elevation and azimuth obtained from the theodolite enable the relative position of the balloon to the theodolite (or point of release) to be determined at any instant, providing the time that has elapsed since the release of the balloon is known.

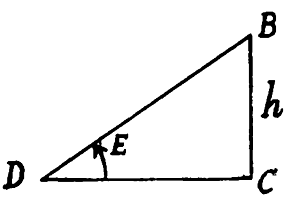


Fig.1

Fig. 1 is the elevation in which D represents the position of the theodolite, B the position of the balloon at the end of, say, the first minute, and C the projection of B on to the horizontal plane through D.

The angle of elevation BDC is known and the height BC (h) is assumed so the horizontal distance travelled (DC) = h cot E.

This gives the displacement of the balloon in the first minute. (Remember we are only concerned with the horizontal travel of the wind.)

4. CALCULATION OF DIRECTION OF DISPLACEMENT

Next the direction of travel has to be obtained. Fig. 2 is a plan in which D is the theodolite position and NS the true north-south line through D and NDX the azimuth angle A at the end of the first minute. (This may be in any quadrant and the same reasoning holds for all figures.)

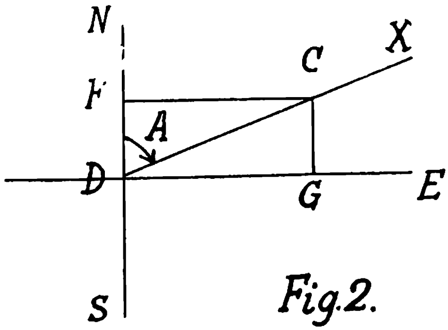


Fig.2.

During this minute the balloon has travelled from D to C, and in doing so has moved both to the north and east, and thus has components in both these directions.

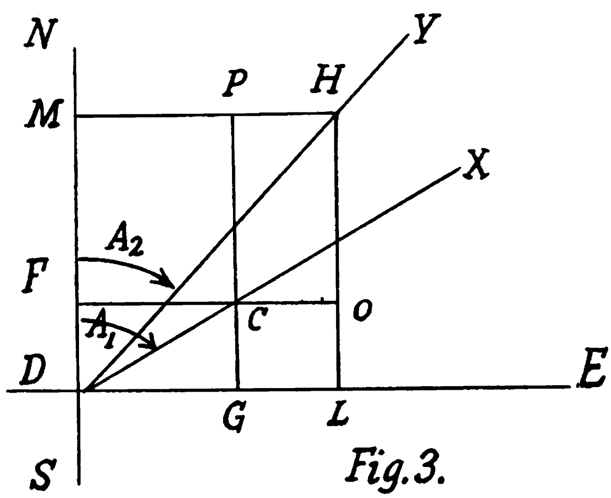


Fig.3.

The easterly component called D_E is DC sin A = FC = DG.

The northerly component called D_N is DC cos A = DF = GC.

Consider now the conditions at the end of the second minute (as we are only concerned with horizontal motion we will only consider the plan of the movement of the balloon).

Starting from Fig. 2, draw the new azimuth angle A_2, i.e., line DY, the position H of the balloon is found from the angle of elevation E and the assumed height (DH = 2h cot E_2 where h = assumed rate of ascent).

From the azimuth angle A_2 the new components of travel for two minutes can be found.

Second easterly component = DL = MH = DH sin A_2.
Second northerly component = LH = DM = DH cos A_2.

These distances represent the components at the end of two minutes, so to find the components for the second minute the components for the first minute must be subtracted. (These components are represented as V_{WE} and V_{SN} on the pilot balloon sheet F115.)

$$V_{WE} = DL - DG = CO = PH.$$
$$V_{SN} = LH - GC = CP = OH.$$

During the second minute the balloon travelled from C to H and since CO and CP are known, the angle PCH and length of CH can be found. This will give the direction and velocity of the wind in the layer from h to 2h units.

From the triangle CPH in Fig. 4 it is obvious—

$$\tan\alpha = PH/PC, \text{ and}$$
$$CH = PH/\sin\alpha$$

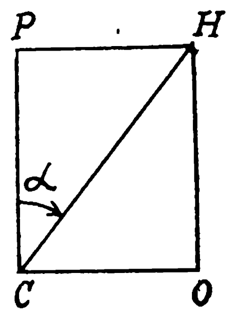


Fig. 4

These may be readily found using the slide rule.

In the same way the components of travel for the third and each successive minute are obtained and compounded to obtain the mean velocity and direction during the minute intervals.

In the discussion only one quadrant was considered, but as the components are really vectors the direction must be taken into consideration, so a convention of signs has been adapted for the components and is shown in Fig. 5.

D_E is always given first to conform with form F.115 which is used for the calculation of upper winds, using the slide rule. When the azimuth angle coincides with one of the main directions, the value and sign of D_E and D_N are:—

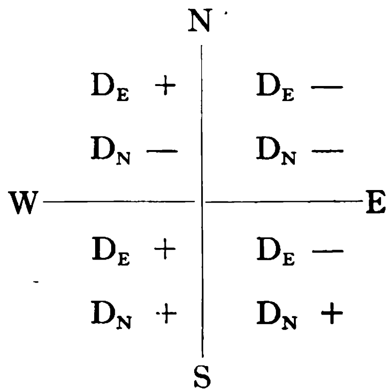


Fig. 5.

AZIMUTH	D_E	D_N
360°	O	$-$ h cot E
90°	$-$ h cot E	O
180°	O	$+$ h cot E
270°	$+$ h cot E	O

When the two vectors V_{WE} and V_{SN} are compounded, an angle of 45° or less is obtained, and then by inspection of the magnitudes of V_{WE} and V_{SN} it can be seen whether this angle must be added to or subtracted from one of the main directions, the quadrant being given by the signs of V_{WE} and V_{SN}.

5. STEPS USING AN ASSUMED RATE OF ASCENT

1. Set angle of elevation on tan scale D.
2. Bring height of balloon on scale C into coincidence with it.
3. Read off $\dfrac{\text{h cot E}}{60}$ at mark H on scale A.

The actual magnitude of $\dfrac{\text{h cot E}}{60}$ is found by inspection.

Suppose h = 1050 metres and E = 20°, then h cot E = 2889 metres, and thus $\dfrac{\text{h cot E}}{60} = 48{\cdot}1$.

(Another way, h cot E is nearly 3000, and this divided by 60 is 50, i.e., $\frac{h \cot E}{60}$ is just under 50.)

Usually once the first $\frac{h \cot E}{60}$ is determined, the subsequent values are evident.

To avoid errors in placing decimal point for the first $\frac{h \cot E}{60}$, the following will be of assistance:—When assumed rate of ascent is 150 metres/minute—

Fig 6

ANGLE OF ELEVATION	$\frac{h \cot E}{60}$
Greater than 88·6°	Less than 0·1°
Between 88·6° and 68·2°	Between 0·1° and 1·0°
Between 68·2° and 14°	Between 1·0° and 10·0°
Less than 14°	Greater than 10·0°

4. Slide $\frac{h \cot E}{60}$ to 90° end of arc on scale A.

5. Consider azimuth angle and enter appropriate signs for $\frac{DE}{60}$ and $\frac{DN}{60}$ (use Fig. 5).

6. Calculate angular difference between azimuth and one of the adjacent main directions (i.e., 360°, 90°, 180° or 270°).

7. Using this difference on scale A, read off values of D_E and D_N (to the nearest 10th of a unit) for values up to 100.

8. Determine from azimuth angle which component D_E or D_N is greater and enter accordingly.

9. Obtain V_{WE}, V_{SN} by subtracting algebraically the successive values of D_{we}, D_{sn} respectively. (For the first line V_{WE} = DE and V_{SN} = DN.)

10. To combine V_{WE}, V_{SN}, place the greater on scale C to coincide with 45° on scale D.

11. Look to the left of this on scale C and find the other and note the angle on scale D coinciding with it.

12. Consider this angle and determine, by the signs of the components V_{WE}, V_{SN} the quadrant to which it belongs.

13. Determine the appropriate half of this quadrant according to which is greater, V_{we} or V_{sn} and enter this direction. (Refer to Fig. 6.)

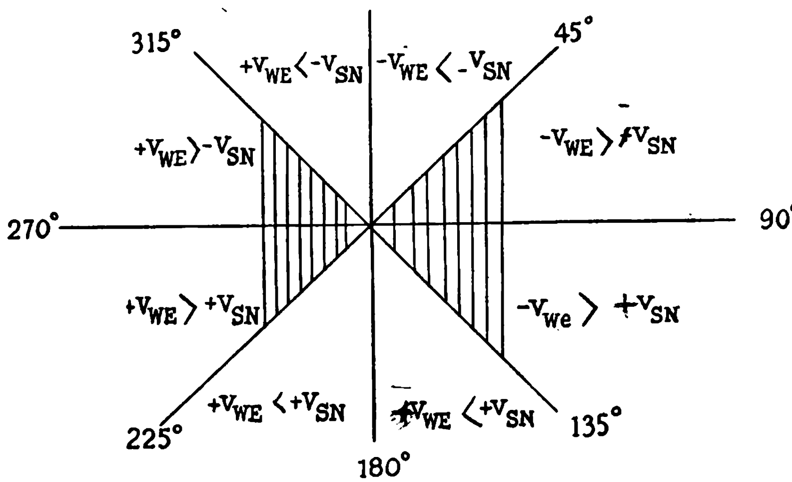


Fig. 7.

If $V_{WE} > V_{SN}$ the angle is in hatched part of figure, $V_{WE} < V_{SN}$ the angle is in clear part of figure.

Find which of the eight segments the V_{WE} and V_{SN} indicate. This will tell whether the angle obtained will have to be added to or subtracted from a main direction, the main directions being 360°, 90°, 180°, 270°.

14. Set the angle found in step 11 on sine scale on scale A.

15. Bring the smaller component of V_{WE}, V_{SN} on scale B in coincidence with it.

16. Read off velocity in kilometres per hour at mark V and enter on form to nearest kilometre—do not use decimals.

17. Read off code figure from mark at 45·8° on scale A (see para. 9)

6. EXAMPLE

PILOT BALLOON ASCENT No. 367

STATION: Laverton.
Height above M.S.L.: 15 m.
Mark for Azimuth: POST.
Bearing: 273·6°.
Reading: 93·6°.
Surface Wind: 5 m.p.h., 180°.

Weight of Balloon: 30 gm.
Colour of Balloon: Red.
Weight of Tail: —
Length of Tail: —
Free Lift: 68 gm.
Ascending Velocity: 150 m/min.

Date: 9/10/41.
Time of Start: 10hr. 45m.
Observer: SGT. EDWARDS.
Computer: F/O WILSON.

Height	No.	Azimuth	Elevation	$\frac{h \cot E}{60}$	$\frac{DE}{60}$	$\frac{DN}{60}$	V_{WE}	V_{SN}	V	Direction
m.		°	°	m.	m.	m.	m/s.	m/s.	k/h.	°
150	1	178·6	49·5	2·1	—0·1	+2·1	—0·1	+2·1	8	179
300	2	170·7	47·4	4·6	—0·7	+4·5	—0·6	+2·4	9	166
450	3	160·7	47·3	6·9	—2·3	+6·5	—1·6	+2·0	9	141
600	4	147·7	46·7	9·4	—5·0	+7·9	—2·7	+1·4	11	117
750	5	137·5	41·0	14·4	—9·7	+10·6	—4·7	+2·7	19	120
900	6	123·4	39·2	18·4	—15·4	+10·1	—5·7	—0·5	21	85
1050	7	118·7	38·5	22·0	—19·3	+10·6	—3·9	+0·5	14	97
1200	8	115·4	39·6	24·2	—21·8	+10·4	—2·5	—0·2	9	85
1350	9	116·6	44·7	22·7	—20·3	+10·2	+1·5	—0·2	5	278
1500	10	110·9	52·4	19·3	—18·1	+6·9	+2·2	—3·3	14	326
1650	11	100·4	60·6	15·5	—15·2	+2·8	+2·9	—4·1	18	325
1800	12	88·6	61·6	16·2	—16·2	—0·4	—1·0	—3·2	12	17

Note the reversal of wind with the rapid rise of elevation, from line 8 to 9, which had previously been decreasing.

Note also that, although the azimuth readings are almost all in the same quadrant, the wind direction has changed through three quadrants.

Note: If the results have been worked out for every second minute, i.e., 300 metre intervals, the velocity obtained must be halved but the azimuth will be correct.

7. ALTERNATIVE METHOD

One step may be eliminated by the following method:—Divide the height by 60 before setting it on scale C opposite the angle of elevation. The steps then become:—

(1) Set cursor on scale D for the elevation.

(2) Divide height by 60 mentally, and set this on scale C to coincide with angle of elevation.

(3) Read off $\frac{h \cot E}{60}$ at end of arc on scale A. The table in Fig. 6 still holds.

(4) Obtain D_E and D_N as for steps 5 and 6 of other method. Note step 4 is eliminated.

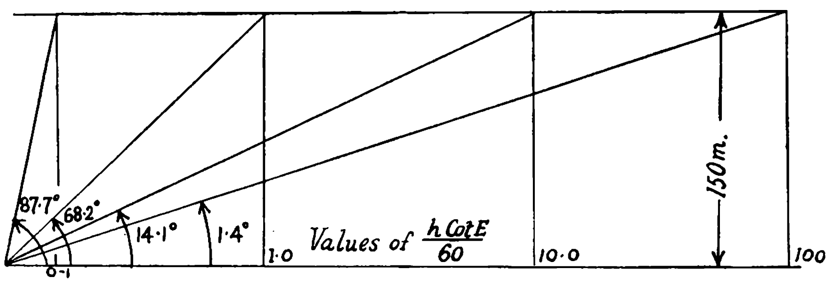
8. MISCELLANEOUS POINTS

(a) Usually the balloon is inflated so that it ascends at the rate of 150 metres/min.; its height at the end of 1, 2, 3 minutes is then 150, 300, 450 metres. Values of the horizontal displacement of the balloon at any instant can thus be obtained.

Using a balloon with a rate of ascent of 150 metres a minute we note the following information:—

Angle of Elevation	Value of $\frac{h \cot E}{60}$	Corresponding Surface Wind	
observed at end of first minute	in metres	m·p·h·	Code Figure
Greater than 88·6°	Less than 0·1	0	0
Between 88·6 and 68·2°	Between 0·1 and 1·0	1-3	1
Between 68·2 and 14°	Between 1·0 and 10·0	4-24	2, 3, 4 or 5
Less than 14°	Greater than 10·0	over 25	6 and over

Values of $\frac{H \cot E}{60}$ of over 100 metres for the first minute are impossible; for a rate of ascent of 150 metres a minute the corresponding angle of elevation would be less than 1·4°.



(b) If two successive azimuth readings are the same, then the wind direction during the interval is—

(i) the same as the azimuth—if the elevation has not increased;

(ii) 180° to the azimuth angle if the elevation has been steadily increasing.

In such cases the wind velocity over the period is the same as the difference in the values of the successive values of $\frac{H \cot E}{60}$ expressed in kilometres per hour.

9. TO OBTAIN THE CODE FIGURE AT THE SAME TIME AS THE FINAL VELOCITY

The code figure is obtained by dividing the velocity in km/hr. by 5, so place 5 on scale B opposite to mark V on scale E, then look to the left on scale B until 1 is found, draw a pencil line to coincide with this; it falls on 45·8° on the sine scale on scale A. To obtain code figure, take nearest whole number to this mark, e.g.,

22 km/hr.	Code figure 4.
6 km/hr.	Code figure 1.
59 km/hr.	Code figure 12.

but as code figure can only be of unit magnitude, this becomes code figure 2 with 50 added to the wind direction.

10. COMPOSITION OF VELOCITIES

Using a slide rule to obtain resultant winds, e.g., compounding thermal and gradient winds:

The components of each wind are found by setting the velocity at 90° end of arc on scale A, and then from the direction obtaining the components with the appropriate sign, the signs being as shown in Fig. 5. The components of each wind are obtained and added algebraically. The resultant components are compounded to obtain the resultant wind.

e.g., find resultant wind of a gradient wind of 25 m.p.h. from 150° and a thermal wind of 12 m.p.h. from 220°.

Wind	D_E	D_N
25 m.p.h., 155° ..	—10·6	+22·6
12 m.p.h., 220° ..	+ 7·7	+ 9·2
Resultant Components ..	— 2·9	+31·8

To compound place 31·8 on scale C opposite 45° on scale D and look to the left on scale C until 2·9 is found opposite 5·2° on scale D. This gives the angle of the resultant to be 175° since D_N is greater and signs are (—) (+). Now place 2·9 on scale B opposite 5·2° on scale A and read resultant velocity (32 m.p.h.) at end of arc on scale A.

Resultant wind is 32 m.p.h. from 175°.

Note: Before compounding winds, make sure that they are in the same units.

11. METEOR CALCULATIONS

For meteor calculations the following steps are followed:—

(1) Set elevation on scale D.

(2) Set height of top of layer on scale C opposite elevation on scale D.

(3) Read off $\frac{h \cot E}{60}$ at mark H.

(4) Transfer this to end of arc of scale A.

(5) From azimuth angle obtain components of travel with appropriate signs.

(6) Enter on working sheet in columns D_E, D_N.

The rest of the procedure is dealt with in the Lecture on Artillery Co-operation.

12. **CALCULATION OF "RANGEFINDER" FLIGHTS**

1. Set elevation on scale E.
2. Set range on mark R on scale D.
3. Read off height from elevation angle on scale E.
4. Set this height opposite elevation angle on scale D.
5. Proceed as for normal flight.

Example

R.F.	Height	No.	Azimuth	Elevation	$\frac{h \cot E}{60}$
392	141	1	197·3	23·0°	5·5
812	280	2	192·2	22·1°	11·5
1125	387	3	186·9	22·1°	15·9

13. **CALCULATION OF "TAIL" FLIGHTS**

1. Set a cursor on the angle of elevation on both the secant scale and the tan scale (both on scale D).

2. Set length of tail on "graticule" part of scale C opposite the angle of elevation on secant scale. (Note the graticule scale increases from **RIGHT** to **LEFT**.)

3. Read off height on scale C at cursor set on tan scale (d) and $\dfrac{h \cot E}{60}$ from mark H.

4. Proceed as for normal flight.

Example

Tail	Height	No.	Azimuth	Elevation	$\frac{h \cot E}{60}$
40·0	122	1	129·8	27·2°	3·9
16·4	261	2	129·3	22·8°	10·3
10·0	396	3	130·5	20·6°	17·5

14. **TO MULTIPLY BY ANY NUMBER ON SLIDE RULE**

1. Set 10 on scale B opposite end of arc on scale A.

2. Move cursor to right (or left) until it is over the number to be used as multiplier.

3. Place number to be multiplied on scale B opposite end of arc on scale A.

4. Read product from cursor set in step 2,

e.g. $21{\cdot}8 \times 5{\cdot}6 = 122$.

Decimal has to be placed by inspection in most cases.

15. **TO DIVIDE**

1. Set divisor on scale B opposite end of arc on scale A.

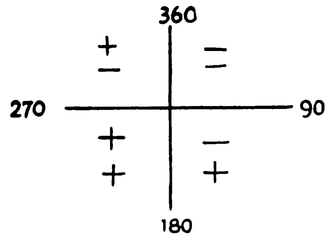
2. Move cursor on scale E until line is over 10 on scale B.

3. Set number to be divided on scale B opposite end of arc.

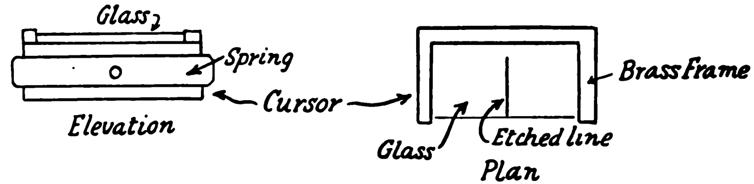
4. Read quotient from cursor set in step 2,

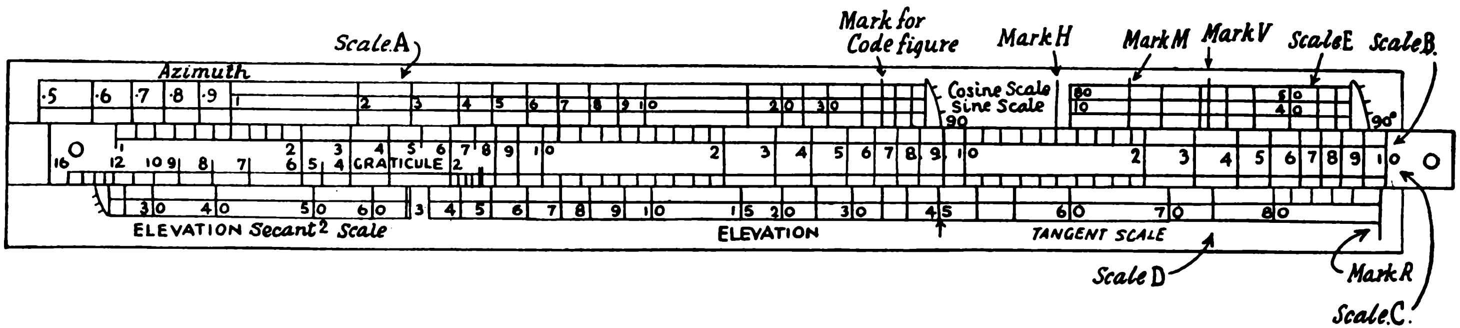
e.g., $126 \div 38 = 3{\cdot}31$.

Decimal has to be placed by inspection.



Sign Convention





Rev. **Pilot Balloon Slide Rule** OBS 30. G.E G.A.

SECTION 16

NIGHT OBSERVATIONS OF UPPER WINDS

When it is required to make observations of the upper winds at night, certain difficulties caused by darkness and poor visibility must be overcome. The standard equipment, i.e., pilot balloon theodolite and gas-filled balloons with assumed rates of ascent are used but means must be provided to—

(a) illuminate the scales (AZ and EL);

(b) illuminate the cross wires on graticule; and

(c) indicate the position of the balloon.

An electrical lighting system is provided on the theodolite to fulfil (a) and (b), while a small paper lantern containing a lighted candle is attached to the balloon to satisfy (c).

LIGHTING SYSTEM ON THEODOLITES

(1) **Pilot Balloon Theodolite, Mark I (Focusing Telescope)**

In this model the batteries, switches and globes are built into the theodolite and no extra attachments for night observations are required. Two toggle switches controlling the lighting circuits are mounted on the right-hand side of the theodolite housing.

(2) **Pilot Balloon Theodolite (Fixed Focus)** (Single telescope type)

Two small dry cell batteries (3 V.) with switch are enclosed in a wooden box which can be attached to one leg of the theodolite tripod. A flexible lead is attached to the battery box and its free end terminated with a plug which can be fitted to a socket provided on the tribrach of the theodolite. From this point wiring is installed to small shielded electric globes mounted on the theodolite. These globes will provide sufficient light to illuminate both scales, the graticule, and the bubble level.

The problem of following a pilot balloon (with lantern attached) at night will be made much easier if the illumination at the theodolite can be reduced to a minimum during successive readings of the scales. Extraneous light is reflected into the eyes of the observer, and as the light from the lantern as seen on the graticule is not very bright any local unnecessary light at the theodolite will add many difficulties. In practice the lighting of the scale and the graticule will only be required when readings are being taken. Between readings the lantern should be held approximately in the centre of the field of view.

ILLUMINATION OF GRATICULE

The hair lines on the graticule of the pilot balloon theodolite are illuminated by an electric globe mounted on the barrel of the telescope. The amount of light falling upon the graticule can be varied by adjusting the position of a reflecting mirror attached to a milled disc mounted on the telescope barrel. It will be found best to have the lighting so adjusted that the graticule lines are just discernible. More light will cause glare in the eyes and make it most difficult to follow the lantern attached to the balloon. When using pilot balloon theodolite, mark I, focussing type, it will be found that the graticule is not illuminated when the wide angle (small) telescope is in use. The reason lies in the fact that the lighting system is connected to the large telescope only.

PRELIMINARY PREPARATIONS

(1) Lighting Gear

If it is intended to carry out pilot balloon observations at night it is most important to check the night lighting equipment, if possible, during the preceding hours of daylight. Make certain that the batteries supplied with the theodolite have sufficient "life" to supply the necessary light. Check the wiring, switches, and globes to locate open circuits or intermittent contacts. Any such faults should be remedied immediately. Thus confusion and inconvenience caused by faulty equipment can be eliminated from the night observation. An electric torch should be included in the equipment supplied for night observations of the upper winds. When using pilot balloon theodolite, mark I (focusing telescope) the hand torch will be necessary to throw light on the bubble during the levelling operation.

(2) Timing the Flight

The readings on the balloon are taken at fixed time intervals, i.e., 1 minute, 2 minutes, etc., as done during a daylight "flight." For the time intervals a watch or an electrical timing buzzer may be used. When using a watch it should be suspended below the azimuth window of the theodolite in such a position that the light thrown upon the azimuth scale will also illuminate the face of the watch. The attention of the observer following the balloon can then be directed to the elapsed time as shown by the watch and accurate intervals of time are easily obtained.

On pilot balloon theodolite, mark I, a small metal hook has been provided on which to hang the watch, but with the older type theodolites it is necessary to bend a short length of wire around the upright standard of the theodolite to obtain a firm suspension for the watch. An office type "glide-on" paper fastener, suitably bent, is a practical solution to this problem.

When an electrical timing buzzer is used at a station, the illuminated watch will not be required as the audible signal will indicate when readings of the balloon should be taken.

(3) **Preparing the Lantern**

It will be an advantage to have a supply of lanterns on hand in readiness for the night flight. Standard type paper lanterns, weight 6 grams, will be supplied. Ordinary household candles are required to provide the light, A length approximately 1½ inches is cut from a candle and the wax pared away to form a wick at one end. This wick is lit and allowed to burn about one minute. It is then extinguished leaving a candle approximately 1 inch long, weight 9 grams. This candle is firmly fixed within the lantern by pushing the point of a drawing pin through the bottom of the lantern at the centre point and thrusting the point of the pin into the wick at the base of the candle.

Attach 2 to 3 feet of strong cotton thread to the wire handle of the lantern for attaching to balloon. The total weight of the prepared lantern may be found, using the new type balloon filler. Place the lantern on the balloon attachment, and move the square section weight to zero on the engraved scale. Adjust for balance by shifting the small circular counterbalance weight and lock when true balance has been obtained. Remove lantern and slide square section weight along the scale until true balance is re-established. Then read scale to ascertain weight of the lantern in grams (approximately 15 grams). It is usual to prepare a stock of lanterns and have them ready for any emergency, such as the candle being extinguished on release or early in the flight.

(4) **Orientation of Theodolite**

For night observations with the pilot balloon theodolite a reference point will be required for orientation. Such a point can be most conveniently found during the daylight hours when the bearing of some object, **which will be illuminated at night,** can be obtained. A fixed marking light or beacon would be suitable. Where no such point is readily obtainable, the bearing of a convenient fixed point, e.g., a fence post at some distance from the theodolite position, could be obtained during the daylight hours. At night, when setting up the theodolite, a torch or similar light placed on the fence post will determine its position, and as its bearing has previously been obtained, orientation can be completed in the usual way.

If orientation must be undertaken at a position with preliminary daylight bearings being obtained, it is possible to use the light on the fence post as before, but its bearings must then be secured by using a prismatic compass. Remember to correct the compass bearing for magnetic declination. At stations equipped with a fixed observation post and metal theodolite cover to protect the instrument from interference, the theodolite can be left in position ready for flights at any time.

(5) **Preparing the Balloon**

The pilot balloon must be filled with sufficient hydrogen to give it the free lift required to rise at an assumed rate of ascent. Account must be taken of the additional load caused by the weight of the lantern.

To Fill the Balloon.—Suppose the weight of the balloon to be 32 grams, the weight of the lantern to be 14 grams, and the assumed rate of ascent to be 150 metres per minute. From the tables supplied the free lift required for a 32 grams balloon at 150 m/min. is 69 grams. But as the hydrogen in the balloon must lift both the balloon and the lantern (total 46 grams) the weight to be lifted is equivalent to that of a balloon weighing 46 grams. From the tables the free lift for a 46 grams balloon is 81 grams.

When filling the balloon it can be done by—

(a) attaching both the lantern and the balloon to the balloon filler and setting 81 grams on the scale of the balance; or

(b) more conveniently by attaching only the balloon to the filler and adding the weight of the lantern to the setting on the scale, i.e., $81 + 14 = 95$ grams.

In case (b) it will be seen that when the true balance is obtained the gas in the balloon is balancing a weight of 95 grams. When the balloon is ready for release the additional weight of the lantern (14 grams) is attached giving the balloon a net free lift of 81 grams as in case (a).

(6) **Release of Balloon.**

Suppose the theodolite to be set up and oriented correctly. To proceed with the flight—

IMPORTANT $\left\{ \right.$ (a) Remove the balloon and lantern to a safe position, i.e., a position known to be well away from any possible danger introduced by an escape of hydrogen from a faulty valve on the gas cylinder or during the balloon filling operation.

(b) Depress the lantern to its original folded position and light the candle.

(c) Take a firm grip of the base of the lantern with one hand and, with the other hand holding the top, return the lantern to the erect position with a quick movement. Make certain that the sides of the lantern are well away from the flame or it will certainly catch fire early in the flight. Then attach cotton to the neck of the balloon.

(d) Take the balloon in one hand and holding the cotton immediately above the lighted lantern proceed to the theodolite position. The lapse of time involved will enable the observer's eyes to become accustomed to the dark.

(e) Hold the cotton taut between the balloon and lantern and at the commencement of the required time interval release them both simultaneously with a fluid upward motion of the arms. If the wind is calm or very light it will be found easier if the thread between the lantern and balloon is held between the thumb and first finger of the right hand so that the thread is taut and vertical or almost so. At the required time interval the thread is released and the lantern will be lifted without any jerk. Any marked interruption in the smooth release of the lantern will immediately extinguish the candle. should the surface wind be strong at the time it will be better to move forward with the wind before releasing the balloon. Should the wind be gusty it will be more satisfactory to await a lull in the wind before releasing the balloon. If the balloon is released in the vicinity of local obstacles, e.g,, hangars, trees, etc., eddying effects will sometimes overcome the rate of ascent of the balloon in the first few seconds following its release and may cause the lantern to bump against the ground. At other times the balloon will be caught in a violent eddy soon after release and will ascend or descend very suddenly. In either case the candle will probably be extinguished and both balloon and lantern are a complete loss. In this case another balloon must be filled and another attempt made.

(f) After the release of the balloon the lantern can be lined up over the open sights of the theodolite and the point of light quickly centred on the graticule. The flight is then completed in the usual way.

(g) All azimuth and elevation angles can be recorded on a piece of stiff card held in one hand. Sufficient light for this purpose will be obtained from the scale illumination on the theodolite.

(h) Should the sky be clear at the time of the observation, and the balloon at some distance from the theodolite, care must be taken not to confuse the lantern with a star. The light from the lantern will appear more "red" than that from the stars and the relative movement of the lantern to the stars should assist the observer to keep it in sight.

(i) After some minutes in the cool air a slight mist may form on either the object glass or the eye-piece of the theodolite. This mist should be removed with a dry cloth from time to time or the light from the lantern will soon become indistinct and the flight brought to a premature close.

SECTION 17

CLOUD OBSERVATIONS BY NIGHT

Before cloud forms may be recognised by night the observer must be able to identify cloud forms by day with confidence. Cloud forms may be identified in two ways at night—by direct visual observations and by indirect observations and inferences, the indirect observations and inferences being the weather at the time, the cloud observed during the preceding daylight hours and the diurnal cloud sequence of the pressure system (if in evidence) or of the local clouds.

In cloud observations at night the moon is of great help both by giving some light to see the clouds and also giving the thickness and motion of clouds passing across its surface. Lights of cities and large towns also assist in identifying low cloud by being reflected from the lower surface of the cloud.

Consider observations made as inferences from the weather at the time. The intensity of showers will indicate the size of cumulus clouds and any thunder or lightning will indicate cumulo-nimbus, steady rain indicates nimbo-stratus or alto-stratus, and drizzle either stratus or strato-cumulus. Fine conditions are more difficult and usually some other indirect observations must be made.

The cloud type during the day, by means of its method of formation, will indicate likely types that may be present at night. Also local conditions will have a great bearing on the clouds that will form and also the time that they may be expected to be in maximum and minimum amounts. Migratory clouds associated with pressure systems will have no relation to the cloudiness caused by local clouds. Many airstreams have characteristic clouds and the airstream may be identified from a synoptic map; the south-westerly stream over southern Victoria is usually accompanied by cumulus cloud and if it has steep gradients the cloud is well developed and of considerable amount.

The first table will help to narrow down the cloud types and the second table may enable the actual cloud type to be identifed.

RECOGNITION OF CLOUD FORMS AT NIGHT (TABLE 1)

Cloud Type	**Observations without Moon**
Ci. Cc.	Some stars bright, some hazy. Cloud illuminated before sunrise and after sunset.
Cs., thin As.	All stars more or less dimmed.
Ac., Sc., Cu.	Stars blotted out in patches and disappearing and re-appearing regularly.
Large Cu. or Cb.	Showers.
St.	Continuous drizzle—light winds.
Sc.	Intermittent drizzle.
Ns., As.	Steady rain—northerly winds.

Cloud Type	**Observations with Moon**
Ci., Cs., Cc.	Thin cloud, moving slowly, moon not hazy.
Thin As. Thin St.	Moon blurred—corona; cloud seems low.
Ac., thin Sc.	Moon clearly visible and then blurred but not obscured.
Cu., thick Sc.	Moon clearly visible—obscured alternately.
Cu. or Cb.	Showers—cloud towering—sides illuminated.

CLOUD FORM AT NIGHT (TABLE 2)

A. Without Moon

Ci. or Cc.	Some stars bright, others hazy; illuminated before sunrise and after sunset and has reddish glow. Hazing of stars may be due to mist or smoke.
Cs.	All stars more or less dimmed and outlines diffused.
Ac.	Stars blotted out in patches and disappearing and re-appearing regularly.
As.	If overcast, stars INVIS ~~visible~~; if broken, some stars visible but no regular appearance and disappearance. Usually accompanied by northerly winds. If thick and lowering, may be accompanied by rain. This stage will be indicated by preceding observations.
Ns.	Lowering of As.—usually with rain and wind tending northwesterly.
Sc.	(a) No cloud above—as for Ac.—but sometimes drizzle may be noticed—winds usually light—over large towns or cities under surface often illuminated by lights. Cloud searchlights will help in identification. (b) Cloud above; unless the cloud is over a well-lit area it will not be discernible without a searchlight.

A. Without Moon (continued)

Cu.	Cannot be distinguished from Ac. or broken Sc. unless well-developed and accompanied by showers.
Cb.	As for Cu. except that thunder and/or lightning may be noticed.
St.	If broken stars visible, cannot be distinguished from As. unless accompanied by misty rain and cold, light or calm winds, and then must be distinguished from Sc. May reflect lights of towns, etc., and appears uniform.
Fn.	Usually discernible because of cloud above.
Fog	Poor visibility—stars may be slightly visible with hazy outlines. Metal filament lamps appear yellowish.

B. With Moon

Ci.	May be seen against moon but light is not affected; a halo may be seen in thick cirrus.
Cs.	Milky appearance around moon; possibly a lunar halo; stars diffused and those near moon possibly invisible.
Cc.	Thin cloud passing across moon and not causing any blur of outline.
Ac.	Small pieces of cloud passing across moon but not obscuring it; edges thinner than centre; no halo but corona may be seen.
As.	If thin, moon vaguely visible and remaining uniform as cloud moves. If thick, moon invisible and possibly light rain. As. usually accompanied by northerly winds.
Ns.	Moon invisible, usually with steady rain and northerly winds, tending westerly.
Sc.	**No cloud above:** Moon obscured for intervals. Thin edges with moon visible through them; sides may be discernible. Lower surface may be illuminated from below over towns. **Cloud above:** If cloud above is broken, same as above. If cloud above is continuous then the Sc. will be invisible unless upper cloud is a cirrus type.
Cu.	Readily seen and distinctive form is visible. If large, may be accompanied by showers.
Cb.	Not discernible unless at a distance; may be confused with large Cu. or layer of As. unless accompanied by thunder and/or lightning.
St.	If thin, moon may be visible; light winds. May be slight drizzle; will reflect lights of towns, etc. If thick, moon invisible; drizzle; light winds.
Fn., or **Scud**	Thin cloud moving rapidly across moon, usually cloud above.
Fog	Moon may be dimly visible; otherwise as for no moon. Lights appear yellow.

SECTION 18

MEASUREMENT OF THE HEIGHTS OF PILOT BALLOONS

Rangefinder and "Tail" Methods

The "free lift" fomula used for determining the rate of ascent of pilot balloons is based upon the assumption that the air in which the balloon is moving has itself no vertical motion. The presence of vertical currents due to thermal (convective) turbulence may obviously greatly alter the height through which the balloon will rise in a given time. While strong convectional currents may extend to great heights (30,000 feet) in the tropics, further south they are generally confined to much lower altitudes and may not be sufficiently extensive to affect the flight of the balloon for periods of more than a few minutes. The presence of strong vertical currents will, of course, be made apparent by the presence of deep well developed Cu. or Cb. clouds. It sometimes happens in south-eastern Australia, for example, strong northerlies near the surface and in the centre of winter anticyclones with frictional subsidence, that due to mechanical turbulence the air has a **downward** motion in the lower layers interfering with the rise of the balloon. On rare occasions over Melbourne rates of ascent have been observed to be as much as 89% more and 50% less than the rates calculated from the "free lift" formula.

In addition to being affected by turbulence the rates of ascent may also vary because of the escape of hydrogen from an improperly sealed balloon.

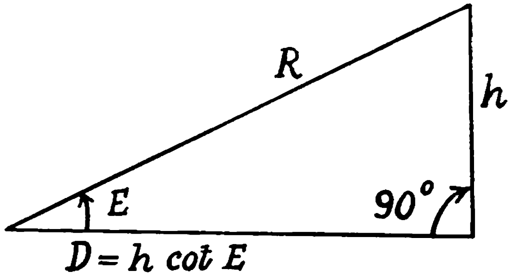
Errors made in the determination of the height of the balloon will cause proportional errors in the calculated displacement (h cot E) and so in the velocity of the wind obtained for the affected layers.

In circumstances where it is not desirable to rely upon an assumed rate of ascent (based on the "free lift" formula) the height of the balloon at each observation can be determined by the use of a rangefinder or the observation of the apparent length of a "tail" suspended from the balloon.

THE USE OF THE RANGEFINDER

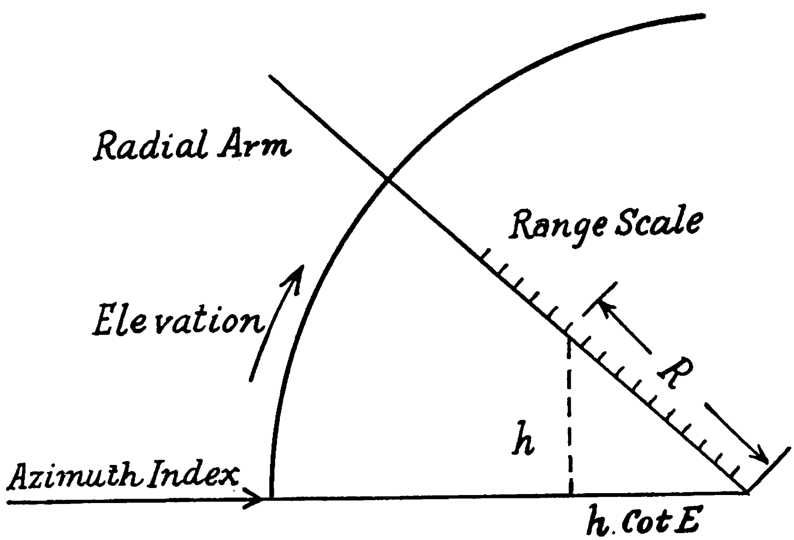
In this method a balloon is released with an assumed rate of ascent and its distance (range) from the station taken at the end of each minute simultaneously with the readings of azimuth and elevation. The instrument generally used is the Barr and Stroud

rangefinder (80 cm. infantry pattern) mounted on a special tripod. An experienced range-taker (with correct vision) can measure distances reliably up to 4000 yards. The range (R) in yards can be converted into metres by multiplying by the factor 0·914 and either the height (h) of the balloon or its displacement (h cot E) obtained by solving a right-angled triangle.



Height: $h = R \sin E$.
Displacement $= D = h \cot E = R \cos E$.

The solution may be conveniently found graphically on the pilot balloon circular calculator if ranges are marked on the radial arm.



As the scale of the calculator is 1 in 30,000 the scale on the radial arm will have to be the same, so that—

$$\begin{aligned} 1 \text{ inch} &= 30{,}000 \text{ inches} \\ &= 833{\cdot}3 \text{ yards} \\ \text{or } 3 \text{ inches} &= 2500 \text{ yards.} \end{aligned}$$

Thus the scale will have to be divided so that every 3 inches represents 2500 yards.

The point representing the horizontal position of the balloon is plotted directly by setting the azimuth scale and the radial arm on the corresponding values of azimuth and elevation angles (as usual) and projecting the point representing the range (on the radial arm) on the index line of the azimuth scale. If in working a change of scale is necessary in order to plot the position of the balloon the same scale change will be necessary on both the radial arm and the height scale, that is, if the range for the first few readings is small and accurate heights are required the range may be doubled or trebled and the heights so obtained will have to be divided by 2 or 3 to get the true height.

Using the slide rule three additional steps are necessary when a rangefinder is used instead of an assumed rate of ascent, also a setting mark is required. To obtain this mark set 9·14 on the sliding scale opposite 45° on the tangent scale and then at the right hand end of the rule draw a line on the bottom scale to coincide with the 100 mark (the last mark on the sliding scale).

To find the height—

1. Set range on mark just found.
2. Set cursor on angle of elevation on sine scale E (see Obs. 14).
3. Read off height from this cursor.
4. Proceed as for normal flight.

i.e., set this height opposite angle of elevation on tangent scale and obtain $\dfrac{h \cot E}{60}$ from mark on upper fixed scale.

If height is not needed then proceed as follows:—

1. Set range on the mark found above.
2. Set cursor on cosine of elevation on scale E.
3. Read at cursor.
4. Transfer reading to end of arc on scale A.
5. Read off $\dfrac{H \cot E}{60}$
6. Obtain components in usual way.

The rangefinder provides a convenient and accurate method of accurately determining the true heights of a balloon but has a disadvantage in that it requires the assistance of an additional skilled observer.

THE USE OF TAILS

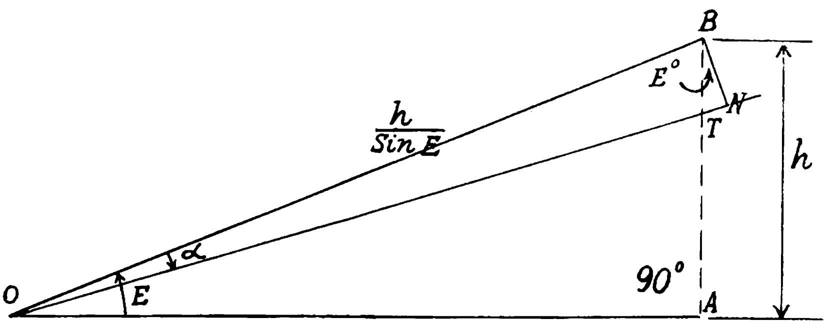
The tail consists of a length of thread (sewing cotton) with a piece of paper attached. The colour of the paper to be used will depend upon the cloud conditions; the paper should be thin, about the size of a piece of foolscap, weight about 10 grams, and be rolled into cylindrical form. The length of the tail is measured from the centre of the balloon to the centre of the pendant; for convenient use of the pilot balloon slide rule it should be 12

metres but in order to give a longer period of observation it may be increased to 24 metres. A small piece of paper should be attached to the thread 6 metres from the centre of the balloon.

When a "tail" is attached to a pilot balloon its weight must be added to that of the balloon before arriving at the value of the "free lift" necessary to cause it to rise at a certain rate (e.g., 150 m/min.). Usually, as is more convenient, the balloon is inflated and balanced against the appropriate weights **before** the tail is attached. If this is done the weight which the inflated balloon **without tail** must support is the sum of (a) the "free lift" appropriate to the desired rate of ascent for the weight of the balloon, together with the weight of the tail **and** (b) the weight of the tail. Thus if the balloon weighs 34 grams and the tail 12 grams, we consider the free lift necessary for a 46-gram balloon, which is 81 grams, but as the tail is not on during the filling we must have an additional 12 grams "free lift" to carry the tail when it is tied on; thus the balloon would have to be inflated to give a "free lift" of 93 grams.

The principle of the tail method is to utilize the relation between the height of the balloon and the angle subtended at the observer's eye by the tail of known length attached to the balloon. It is useful when the wind is fairly strong so that the elevation of the balloon does not exceed 40°, but is not applicable when the elevation is large.

Suppose the balloon B is at height h (= AB) with elevation E°, that the length of the tail is t and that the tail subtends a small angle α :—



In the right-angled triangle BTN, BT = t the length of the tail, the angle TBN is equal to the angle TOA which is practically the same as E.

BN = BT cos TBN = BT cos TOA = BT cos E = t cos E. Further in the right-angled triangle BOA, BA = h, the height of the balloon and

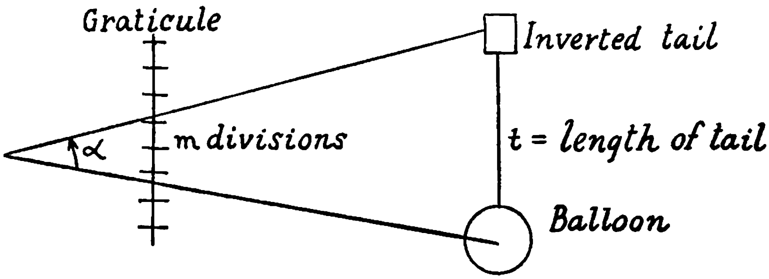
$$BO = \frac{BA}{\text{Sin E}} = \frac{h}{\text{Sin E}}$$

Again, in the small sector BON

$$\alpha = \frac{BN}{OB} = \frac{t \cos E}{h/\sin E} = \frac{t \cos E \sin E}{h} = \frac{t \sin 2E}{2h} \text{ radians}$$

since $\sin 2E = 2 \sin E \cos E$, so that $H = \dfrac{t \sin 2E}{2\alpha}$ .... (1)

The angle α is measured by using a graticule in the focal plane of the objective of the telescope. The tail is observed with the telescope and its apparent length, in terms of the dimensions marked on the graticule, is determined simultaneously with the readings of the elevation and azimuth angles at each time of observation.



If the apparent length of the tail is **m** divisions, and K divisions on the graticule subtend an angle of 1 radian, then the number of radians = m/K. Substituting this in (1) we get $h = \dfrac{Kt \sin 2E}{2m}$

K is a constant of the theodolite (10^3) and for convenience of calculation Kt is made equal to $1 \cdot 2 \times 10^4$ and t equal to 12 metres or some integral multiple of 12 metres.

The values of the height and the corresponding displacement (h cot E) may be obtained from tables, graphically, or calculated on a slide rule. The graphical method involves placing the radial arm of the pilot balloon circular calculator on the appropriate elevation setting across a series of curves or a nomogram marked in graticule scale divisions. (See A.M.S. Circular 19.)

The steps necessary when using slide rule are:—

(1) Set cursor on angle of elevation on secant scale and on tangent scale, both on scale D.

(2) Set the length of tail on graticule scale opposite the elevation on secant scale. (Note the graticule scale reads from **right** to **left**.)

(3) Read off height from cursor on tan scale D and $\dfrac{h \cot E}{60}$ from usual mark on upper scale.

(4) Proceed with calculations in the usual manner.

The theory of the method assumes a vertical tail, but in practice the tail swings and in general lags behind the balloon and best results are obtained if the following routine is followed. As the time of observation approaches the balloon should be centred on the cross wires and kept there for about 5 seconds before readings are to be made, during which time the tail should be watched closely and the reading accepted is to be the maximum length that the tail has presented during that short interval, and it is given to the nearest tenth of a graticule division. Azimuth and elevation angles are then read.

It may be found that in the early stages of the ascent all the tail is not visible in the field of view; when this occurs measure the apparent length from the centre of the balloon to the piece of paper attached to the thread at the 6-metre mark and multiply the number of graticule divisions by 2 (with a 12-metre tail) or by 4 (with a 24-metre tail). As soon as the long tail has come completely into the field of view observations should be made upon it.

If using the low power telescope on a Mark I theodolite the graticule reading must be multiplied by 4 before calculating the height of the balloon.

In order to avoid errors due to the swinging of the tail and surface turbulence, the heights obtained during the first three readings should be averaged **before** proceeding with the calculations of the h cot E and velocity.

When the balloon ascends beyond the height at which the length of the tail can be satisfactorily observed the future rate of ascent should be taken as the average of the last three height intervals obtained from the length of the tail.

SECTION 19

ARTILLERY CO-OPERATION

(See " Handbook of Meteorological Co-operation with Artillery," pages 1-4.)

SECTION 20

BALLISTIC WINDS AND TEMPERATURES FOR ANTI-AIRCRAFT FIRE

(a) **Ballistic Winds**

See "Handbook of Meteorological Co-operation with Artillery," and Artillery Co-operation pro forma, Book 6.

(b) **Ballistic Temperatures**

See "Handbook of Meteorological Co-operation with Artillery," and Artillery Co-operation pro forma, Book. 5.

SECTION 21

BALLISTIC WINDS AND TEMPERATURES FOR FLAT FIRE

(a) **Ballistic Winds**

See "Handbook of Meteorological Co-operation with Artillery," and Artillery Co-operation pro formas, Books 2 and 4.

(b) **Application of Ballistic Wind Reports**

The following data are given to indicate the corrections to range and deviation by applying calculated ballistic winds. The corrections that are given are for 10 feet per second winds. For other wind velocities the corrections are proportional to the corrections for 10 feet per second winds.

(i) The corrections for 10 feet per second winds with B.L. 60 pdr. firing with ranges of 5,000 yards and 10,000 yards with full charge are given below:—

Range	Correction
5,000 yards	13·5 yards
10,000 yards	58·8 yards

When firing with half charge and range of 5,000 yards the correction is 30·4 yards.

(ii) The corrections for 10 feet per second winds with 18 pdr. gun firing with ranges of 3,000 yards and 6,000 yards are:—

Range	Range Correction (winds in same direction as line of fire)	Line Correction (winds at right angles to line of fire)
3,000 yards	17 yards	7 yards
6,000 yards	57 yards	23 yards

(iii) The correction for 10 feet per second wind with 4·5 inch howitzer (5th charge) firing with ranges of 3,000 yards and 6,000 yards are:—

Range	Range Correction (winds in same direction as line of fire)	Line Correction (winds at right angles to line of fire)
3,000 yards	11 yards	4 yards
6,000 yards	38 yards	21 yards

(c) **Ballistic Temperatures**

See "Handbook of Meteorological Co-operation with Artillery," and Artillery Co-operation pro formas, Books 1 and 3.

SECTION 22

UPPER WINDS, PRINCIPLE OF OBSERVATIONS, ACCURACY OF OBSERVATIONS, INTERPRETATION AND SIGNIFICANCE OF PILOT BALLOON CALCULATION

THE PRINCIPLE OF PILOT BALLOON OBSERVATIONS

The determination of upper winds from pilot balloon observations is based on the assumption that the mean wind velocity in a layer is represented by the displacement of a pilot balloon between its positions at the bottom and top of the layer, and that this mean velocity may be applied at the mean height of the layer.

The main limitations which arise from this method of measuring upper winds are:—

(1) The mean wind velocity may not be applicable to the mean height of the layer.

(2) The mean wind velocity may correspond to a different height from that for the mean wind direction.

(3) The fortuitous movement of a balloon through a particular layer results in the determination of the mean wind velocity during a particular period of time. As the mean wind velocity in a layer varies with time, the calculated velocity is not truly representative unless it happens that the balloon is borne by the mean wind during its passage in the layer.

(4) It may happen that the calculated velocities are representative only of the horizontal area through which the balloon has been carried during the period of observation.

ACCURACY OF OBSERVATIONS

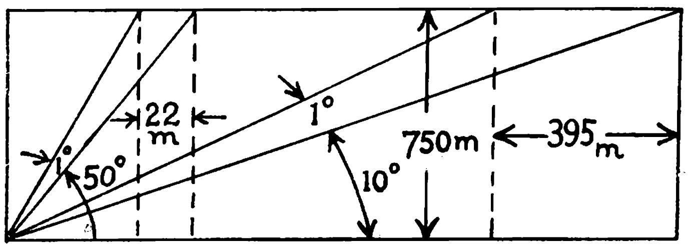
The observations on the theodolite of the pilot balloon should be taken with the greatest possible accuracy. The observations concerned are the angles of azimuth and elevation and the time intervals between readings. As the assumed height of the balloon depends upon the time which has elapsed since the release of the balloon, the readings should be made at exactly one minute intervals unless half or two minute observations are being made for Meteors for Artillery Co-operation.

Errors that may occur are, in order of importance, as follows:—

1. Errors in elevation.
2. Errors in azimuth.
3. Errors in the time intervals.
4. Errors in height due to actual rate of ascent differing from assumed rate of ascent.

(1) **Errors in Elevation**

These become increasingly important at low elevation and at great distances, that is, after the flight has been in progress for some time. This can be seen from the diagram. If the balloon is at an elevation of 50° at the end of 5 minutes, the height will be 750 metres and an error of 1° will cause an error of 22 metres in the position, but if the angle of elevation was 10° at the end of 5 minutes, the same error of 1° will cause an error of 395 metres, which is very considerable. This is a variable error.



(2) **Errors in Azimuth**

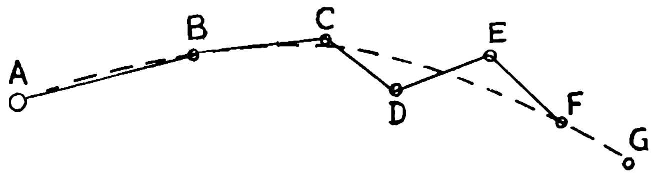
The effect of an error in azimuth depends entirely upon the distance of the balloon from the theodolite, but as the errors in azimuth are usually large, the effect can be appreciable even in the early readings.

At a distance of 2000 metres an error of 1° in azimuth will cause a sideways displacement of 35 metres while at 6000 metres the displacement has become 105 metres.

The accuracy of the elevation and azimuth readings are dependent upon the accuracy of the initial levelling and orientation of the theodolite, so the greatest care should be taken in carrying out this operation.

The wind direction and velocity calculated from a pilot balloon ascent will change more or less regularly from one interval to the next and any sudden change or reversal should be investigated and if the theodolite readings do not indicate any sudden change, the calculations should be checked. If the velocities are very light, marked changes in the direction are possible from one reading to the next. If in a flight the calculated directions are moving steadily in some direction and one calculated direction departs markedly from this trend, a check of the calculation should be

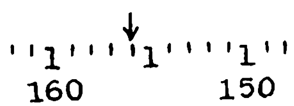
made, and if no error is found then an error in reading of either or both elevation and azimuth must have been made. This is illustrated below.



Point D is obviously out and this also makes point E incorrect as an error in h cot E affects **two** lines. See-sawing of directions is usually due to an error in reading an azimuth angle.

"See-sawing." Mean direction should be taken.

Care should be taken in readings of azimuth near the middle of the "tens" groups. The azimuth scale is graduated from the right to the left as shown and a common error is to read 156° as 164°, etc.



Azimuth Scale.

Any errors detected and which are apparently due to an incorrect reading of either or both of the angles should be smoothed out by taking the mean direction and velocity of the period before and after that in which the error was made.

(3) **Errors in Timing**

As the balloon is usually inflated to ascend with a velocity of 150 metres a minute, an error of 8% will be caused in the calculated wind velocity if the readings are made 5 seconds before or after the correct instant. If one reading is made 5 seconds late and the next reading is made on time, the actual distance that the balloon has risen since the previous reading is only 138·5 metres and the velocity obtained will be too low. Small errors in timing are not likely to cause large errors in the calculations but it is a source of error usually overlooked.

Suppose an error is made in the timing of the observations. Then the following effect will be produced. Suppose that A is the position of the balloon at the end of one minute period and the next reading is made late. The balloon will then be at, say, B.

If the following reading is made on time again at C we assume, in the calculations, that the balloon is at D mid-way between A and C. Thus the calculated velocity will be too great during the first period and too little during the second period. Thus any sudden changes in calculated velocity, unless obvious from the movement of the balloon itself, indicate an error, most likely in the time interval but also possibly in either azimuth or elevation angles.

```
A             D   B             C
O— — — — — —O— —O— — — — — —O
```

A sudden change in the movement of the balloon is evident to the observer at the theodolite and he should immediately notify the calculator of any such changes.

It is of interest to know what effects on the accuracy of the result, various small errors in the position of the balloon may have.

A wind of 1 mile per hour corresponds with a movement of approximately 26 metres per minute. Therefore if the position of the balloon is observed correctly at the end of one interval and 26 metres in error in the next, an error of 1 m.p.h. is introduced.

(4) Errors in Height

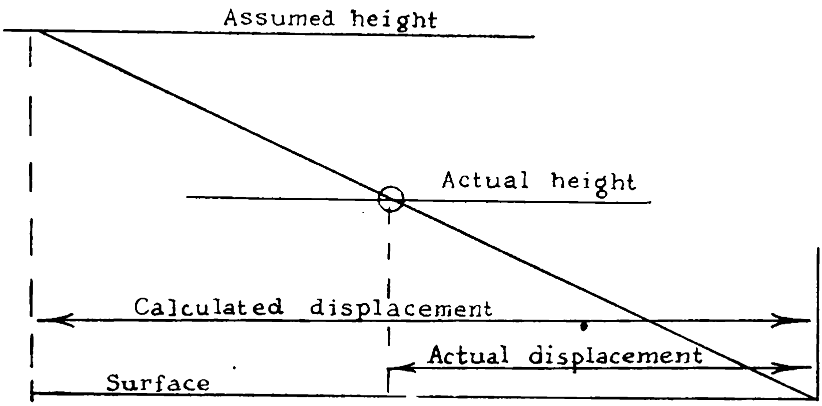
These may be of several kinds:—

(a) Due to incorrect inflation. This causes a constant error in the calculated velocity of the wind and is proportional to the deviation from the correct rate of ascent. For example, if the rate of ascent is 140 metres per minute, instead of 150, all the calculated velocities will be too high in the ratio of 15 to 14. Also the heights to which the winds are ascribed will be incorrect by the ratio 14/15.

(b) Due to ascending or descending currents. These are only likely to affect the flight for a short period and thus the wind speed for perhaps two or three periods is in error and the error is dependent upon the magnitude of these unusual currents. Such currents are possible on warm days when convectional clouds are well formed, also over towns and rugged country where turbulence and eddies will be formed in a stream moving with moderate velocity. Errors such as these are difficult to identify as in such cases the wind is usually gusty. This error is usually variable.

THE EFFECTS OF A DECREASE IN THE ASCENSIONAL VELOCITY

If the actual rate of ascent is slower than the assumed rate, the calculated velocities are larger than those of the actual wind.



This effect may be brought about by—

(a) Permitting the balloon to be caught in a strong, stationary eddy at the time of release.

(b) Down currents in the atmosphere.

(c) Incorrectly using a smaller free lift than is required, e.g., neglecting to add the weight of the tail or lantern when determining the balancing weight to be used.

(d) Carelessness in balancing the balloon so that it is insufficiently inflated.

(e) Leakage of hydrogen from the balloon.

(f) (To a smaller extent) by distortion of the balloon.

(g) (To a smaller extent) by the drag of a tail or lantern.

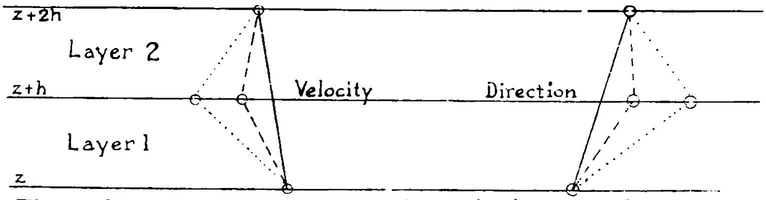
Whenever unexpectedly strong wind velocities are obtained a "back check" should be made to ensure that the balloon has not been affected by any of these accidents.

The reverse is caused by an increase in ascensional velocity of the balloon. Causes (e), (f), (g) will not apply obviously in this case.

VARIATIONS OBTAINED BY THE USE OF PILOT BALLOONS RISING WITH DIFFERENT VERTICAL VELOCITIES

Different "wind velocities" may be obtained for various layers by using pilot balloons with different rates of ascent, even though the pilot balloons truly reflect the mean wind velocities of the layers in question.

The dotted lines represent the travel of the slow balloon, the broken lines represent the travel of the fast balloon and the continuous line the mean travel for both balloons through the same **height** 2_h.



The effect can be seen from the calculations of the winds in layers (1) and (2) based on the observation of two balloons, one rising at twice the vertical velocity of the other. Both sets of observations give exactly the same mean wind velocity through the double layer, but it is seen that the velocities calculated from observations of the slowly moving balloon may differ considerably from those representing conditions in the double layer.

The effects will appear much more complicated if it happens that the rate of ascent of the fast balloon is not an integral multiple of the rate of ascent of the slow balloon.

Results obtained from pilot balloon observations may be reliably applied only to the layers of observation. Usually, however, the changes in velocity or direction are sufficiently uniform to enable the determination of a mean wind velocity through a number of layers. To be most satisfactory, observations should be made through thinner layers than those for which the mean winds are required.

SIGNIFICANCE OF RESULTS AND INTERPOLATION FOR STANDARD LEVELS

Consider this short flight:—

Height	No.	Azimuth	Elevation	V_{WE}	V_{SN}	V k/hr.	Direction	Mean heights to which velocities are related
150	1	352·0	15·7	+1·2	−8·8	32	352°	75 metres
300	2	347·3	12·6	+3·7	−13·2	49	344°	225 metres
450	3	340·0	11·7	+7·5	−12·3	52	329°	375 metres
600	4	333·2	10·9	+11·0	−12·2	59	318°	525 metres
750	5	327·4	10·9	+11·5	−8·3	52	306°	675 metres

The actual components at 150, 300, 600 metres will be obtained by taking the mean of the components ascribed to that height and the height above. These components and the corresponding velocity and directions are shown in this table:—

Height	V_{WE}	V_{SN}	Velocity	Direction
150	+2·5	− 11·0	40 k/hr.	347°
300	+5·6	− 12·8	50 k/hr.	336°
600	+11·3	− 10·3	55 k/hr.	312°

Each value of velocity represents the mean velocity of the balloon during the previous minute, e.g., during the first minute while the balloon was rising from the level of the station to 150 metres, the mean velocity was 32 kms. per hour from 352°. In the second minute the balloon was rising from 150 to 300 metres; the mean velocity, i.e., at 225 metres, was 49km/hr. from 344°, but the actual wind at 150 metres was 40 km/hr. from 347°, and at 300 metres, 50 km/hr. from 336°.

In general the mean velocity derived for the velocity of the balloon during a particular minute, or other interval of time, represents the mean velocity of the wind at the mean height of the levels at the beginning and end of the period.

The mean wind at any particular level may be found by interpolating between the components of the velocities for the nearest mean heights and then compounding the values so obtained, as illustrated above.

The degree of accuracy necessary for aviation purposes does not call for precise interpolation and in order to save time and avoid errors of interpolation it has been decided to report the winds, as calculated at the top of the layer rather that at the mean height of the layer.

For artillery meteor reports, however, every possible degree of precision is necessary and any necessary interpolation must be carried out.

DETECTING AND "SMOOTHING" OF ERRORS

Because of the inability of the atmosphere to support large shearing stresses, the variation of winds with height must be gradual and any sudden changes in direction, particularly reversals or velocity, must be regarded with suspicion as they are possibly, but not always, due to errors of observation or calculation. Any noticeable inconsistent result should be smoothed to fit in with the general trend as indicated by prior and subsequent results.

Points which will assist in an analysis of pilot balloon calculations:—

1. At the end of the first minute the direction is the same as the azimuth.

2. The velocity, during the first period, is obtained by setting the value of h cot E on the end of the arc on scale A and reading the result at mark V.

3. The magnitude of the velocity cannot be less than the increment in the value of h cot E expressed in km/hr.
4. If the observed azimuth at two successive readings is the same, then—
   (a) The velocity is obtained by converting the change in the value of h cot E to km/hr.
   (b) If h cot E is increasing, the direction of the wind is the same as the azimuth. If the value of h cot E is decreasing, that is, the balloon is approaching the station, the direction of the wind is obtained by adding 180° to the azimuth.
5. If the successive angles of elevation are decreasing or only slightly increasing the balloon is going away from the station and h cot E should be increasing.
6. If the angle of elevation is increasing steadily the balloon is approaching the station and the value of h cot E should decrease.

SECTION 23

MEASUREMENT OF HEIGHT AND MOVEMENT OF CLOUD

A. MEASUREMENT OF HEIGHT OF CLOUD

Cloud heights may be estimated with reasonable accuracy after experience has been gained, but in order to check the estimation methods of measurement are necessary.

Measurement of the height of isolated cloud is often difficult, but overcast skies and well broken cloud is able to be measured with fair accuracy.

1. The most common method is to use a "ceiling" balloon **and** obtain the time it takes to enter cloud. A "ceiling" balloon usually weighs 10 grams and is inflated to give a rate of ascent of 125 metres per minute (400 feet). This requires a free lift of 22 grams.

The best way is to follow the balloon with the theodolite to make sure that the balloon does enter the cloud and is not obscured by mist or rain. If the cloud is low it can often be followed into the cloud without the theodolite.

The height of cloud will often be found when making pilot balloon observations and, of course, there is no need to send up a separate "ceiling" balloon. The "ceiling" balloon is only useful for overcast or well broken cloud.

2. **Cloud Searchlight.**—The searchlight is set up so that the beam is at an angle of elevation of 63° 26′. This is found to give the greatest accuracy over the important range of cloud heights (up to 2000 feet). Then from the other end of a base line of predetermined length the angle of elevation of the spot of light on the cloud base is found by clinometer. Then from the table supplied with the searchlight, the height of the cloud is found. The portable searchlight with a vertical beam needs a base line of 1000 feet for clouds over 2000 feet, for accurate results.

Care should be taken to keep the searchlight glass clean and see that the focus is correct. Prolonged use is detrimental and thus readings should be made quickly and the light switched off as soon as the spot is sighted. A mean of three readings should be taken.

Accuracy is necessary in obtaining the angle of elevation of the spot particularly if the observer's back is to the light, as the errors possible increase very rapidly with the decrease of elevation

(see example). For the searchlight at C.W.B. the base is 712 feet and errors of 1° at various elevations are shown in this table.

Case 1 (Facing Light)			**Case 2** (Back to Light)		
Elevation Degrees	Height Feet	Error Feet	Elevation Degrees	Height Feet	Error Feet
65	736	—	65	21,360	—
66	753	17	66	12,958	8402
75	927	—	75	3,062	—
76	948	21	76	2,848	186

Notice the small error caused by 1° at the lower heights and also the greater error in Case 2 observations. It is doubtful if the spot on the cloud can be seen if the base of the cloud is over 10,000 feet, but then the height of the cloud has ceased to become important. The usual base line is either 500 or 1000 feet, depending upon the conditions and obstructions at the particular site.

3. **Simultaneous Sighting on Clouds by Two Observers at the End of a Measured Base Line.**—Most of our knowledge of average cloud heights was obtained, before the development of organised meteorological services, by this method. The method is identical with the double theodolite observations on pilot balloons and the working is somewhat involved and will not be possible in normal station routine.

B. MEASUREMENT OF VELOCITY AND DIRECTION OF CLOUD MOVEMENT

For determination of the movement of cloud some form of nephoscope is used. They will give the direction of movement and the angular velocity which, if the height is known, will give the linear velocity of the cloud. Actually a ratio is obtained between the velocity of the cloud and its height. This is called the velocity-height ratio, and is independent of the distance of the observer from the point vertically beneath the cloud.

Nephoscopes are of two types, direct vision (Besson's) and reflecting (Fineman's). These will be treated separately.

1. Besson's Comb Nephoscope

This consists of a vertical rod which has at its upper end a crosspiece 3 feet long which has spikes on it at equal distances from a central one. The vertical rod is mounted so that it may be rotated by an observer, standing away from it, moving cords attached to a short crosspiece. The rod should be adjusted for height so that the mark on the rod is at the eye level of the observer.

When using the apparatus the observer takes up a position so that the selected portion of a cloud is in line with the central spike, then remaining motionless himself, rotates the comb by the attached cords until the cloud appears to travel along the tips of the successive spikes, the direction of the cloud is then read off the direction plate.

The velocity-height ratio is found by taking the time for the portion of the cloud to pass from spike to spike. If "t" be the time taken for the cloud to move between spikes "a" feet apart, and "b" feet the distance from the top of the central spike to the level of the observer's eye the velocity-height ratio is a/bt. Both "b" and "a" must be in the same units. Some form of glare glasses are necessary to protect the observer from the sun. It is of utmost importance that the observer keeps his head still during the observation and, if possible, some form of "steady" should be used.

If the height of the cloud is known then the velocity will be obtained by multiplying the height by the ratio found.

The spikes are usually arranged so that a pair subtend an angle of 3° at the eye of the observer. This makes the spikes 3 inches apart at a distance of 7 ft. 6in. As the distance between the spikes and the height are constant then the velocity-height ratio depends only on the time and so a table may be made up to give the value of the ratio for any time interval.

The ratio is usually expressed in radians per **hour**, so that if the time is taken in seconds the ratio must be multiplied by 60×60 to bring it to hours.

Any unit of height may be used in the ratio and the velocity obtained will then be in that unit.

$$\frac{d}{h} = \frac{a}{b} \text{ but } d = v.t.$$

$$\text{thus } \frac{v.t.}{h} = \frac{a}{b}$$

$$\text{i.e. } \frac{v}{h} = \frac{a}{b.t.}$$

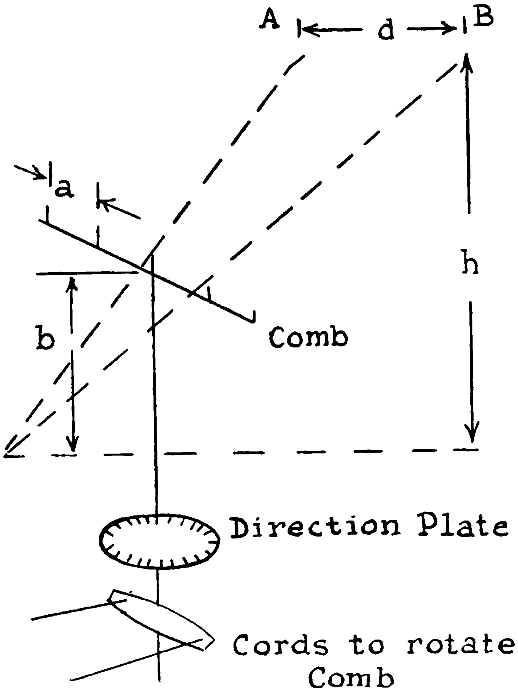
If $a = 6$ in., $b = 7$ ft. 6 in. and time is 20 secs.

$$\frac{V}{h} = \frac{\frac{1}{2}}{7\frac{1}{2}} \times \frac{1}{20} \text{ radians per sec.}$$

$$= \frac{1}{15} \times \frac{60}{20} \times \frac{60}{1} \text{ radians per hour.}$$

If the height of the cloud is 3 miles then the velocity is—

$$v = \frac{1}{15} \times \frac{60}{20} \times \frac{60}{1} \times \frac{3}{1} \text{ miles per hour} = 36 \text{ m.p.h.}$$



2. **Fineman's Mirror Nephoscope**

This consists essentially of a disc of black glass mounted on a tripod stand which allows accurate levelling. A vertically adjustable pointer is attached to a collar that can be moved independently of the mirror. A scale on the side of the pointer gives the height of the tip above the level of the glass.

The method of use is as follows:—

The glass disc is levelled and then oriented, remembering the magnetic declination, and also that in the southern hemisphere 180° is set on north. The observer then moves himself until the image of the cloud and the tip of the pointer coincide in the small circle on the glass. Some adjustment of the pointer will be necessary to do this. The observer then moves his head so as to keep the images in coincidence and the point at which the image apparently leaves the disc gives the direction of movement of the cloud. The velocity height ratio may be found by noting the time in seconds that it takes the image to move from the small to the larger circle.

The velocity height ratio for this nephoscope is the same as for the comb nephoscope but the symbols now become:—

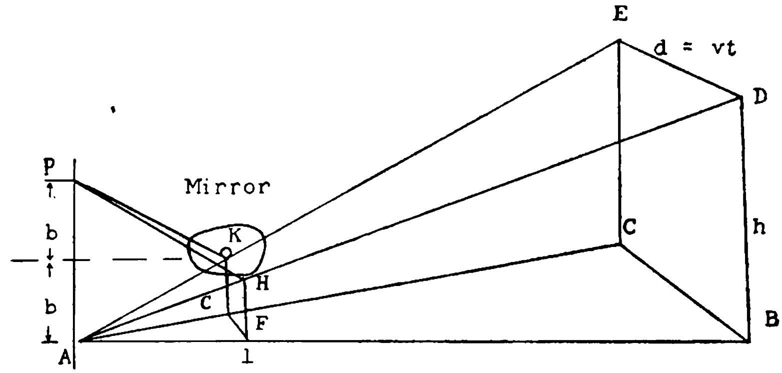
"a" the difference between the radius of the two circles.

"b" the height of the tip of the pointer above the reflecting surface.

"t" the time for the cloud image to pass from the inner to outer circle.

The velocity-height ratio is given in radians per hour.

Diagrammatic representation. Cloud moving from D to E.



A = Reflection of tip of pointer in mirror

a = Difference in diameter of circles

In the triangle ABD and AHF, $\dfrac{v.t.}{a} = \dfrac{DA}{HA}$.

In the triangle ADB and AHF, $\dfrac{h}{b} = \dfrac{DA}{HA}$

Thus $\dfrac{v}{h} = \dfrac{a}{b.t.}$

This diagram is not to scale, but only to give an idea of the geometry involved. The same reasoning holds if the pointer is on the same side of the centre of the mirror as the cloud.

A table for use with this nephoscope is given in the British Observer's Handbook, page 149.

C. **CLOUD OBSERVATIONS BY MEANS OF THE P.B. THEODOLITE**

Low cloud is not always overcast and, even when overcast at time of P.B. observations, higher clouds may be present at some little time previously. The observer should record middle and higher cloud movement whenever convenient. He should keep a continuous record or diary of the movement of upper and middle clouds in particular, and in this way he will have some information on hand when suddenly confronted with low, overcast sky.

1. Cloud Types

The best clouds for observing by the P.B. theodolite are the upper and middle clouds, and particularly Ci., Cc. and Ac. On the whole, low clouds are not so suitable. Lenticular clouds should be avoided, for being the crests of more or less stationary waves in the atmosphere rendered visible by condensation, their movement is not representative of the motion of the free air.

2. Method of Observation

The cloud selected should be unchanging and well defined, with a sharp point or corner that can readily be recognised in the field of view. For convenience, it is advisable to select clouds about midway between horizon and zenith, but good observations are possible when the angle of elevation lies between 10° and 70°.

Having selected (often by the naked eye) the cloud point to be followed, this point is then centred in the cross wires and followed in the same manner as a balloon, readings of azimuth and elevation being made at half or one minute intervals.

Observation over one minute is frequently sufficient, but, on the other hand, it is advisable to extend the observation over several minutes and mean the results. Or without taking intermediate minute readings, the cloud may be observed over a period of two, three or more minutes. It is important for long period observations to ensure that the cloud does not change shape, so that the original point selected is not lost to view either by its being absorbed in a developing cloud mass, or by its vanishing completely, or being hidden by lower clouds. If observing Ac., which is more likely to change its form than Cc., it would perhaps be advisable to use short period observations such as half minute intervals. Cc. is more suitable for longer period observations such as one minute intervals.

In these observations, greater concentration is in general needed than for following a pilot balloon. After 15 seconds or so the eye gets tired, vision becomes less efficient and the cloud point, however clear it may have been at first, becomes indefinite, and appears to merge imperceptibly into a whitish background. All this can be avoided, and the observation made simple, by turning the elevation screw backwards and forwards between readings, and in this way, the cloud point by moving up and down in the field of view retains its contrast with the background and may be followed without effort and need be centred only when a reading is required.

Records of practical value may be obtained under difficult conditions by observing cloud over the rough sights. In this case observations should be made over intervals of some minutes. When cloud is moving from the observer, or if elevation is decreasing without azimuthal change, the cloud direction may immediately

be read off from the angle of azimuth. If, however, cloud is approaching the observer without azimuthal change, elevation increases and direction of cloud movement is given by (azimuth — 180°). This method will give a ready and reasonably accurate method of obtaining cloud direction but not speed, which, however can be given in general terms such as fast, medium or slow.

3. Cloud Height

The height of the cloud to be observed has to be estimated. Cloud heights may sometimes be obtained from incoming pilots. Once estimated, the cloud height is assumed constant throughout the computations.

The heights to be assumed for upper and middle clouds vary with the appearance of the clouds, with latitude and with the time of the year. Generally upper clouds are found between 6 and 10 kilometres, and middle clouds between 2 or 3 and 6 kilometres.

In estimating cloud heights, the use of known mean heights at the particular station will be helpful. If no mean heights are specified at a particular station the international limits should be used, bearing in mind that heavy, thick cloud is lower than thin cloud of the same type. Any error in estimating the height has little effect on the calculated direction. The percentage error in estimating cloud height will give a percentage error in the calculated velocity and direction that is not so large as to be impracticable.

In order to facilitate computation on the slide rule and to comply with the "neph" code and upper wind reports, it will be found convenient to estimate the height of the cloud to the nearest kilometre (1 kilometre = 1000 metres = 3300 feet).

If cloud is estimated at 6-7,000 feet, then 2 kms. (2000 metres) might be used.

If cloud is estimated at 8-11,000 feet, then 3 kms. (3000 metres) might be used.

If cloud is estimated at 12-14,000 feet, then 4 kms. (4000 metres) might be used.

If cloud is estimated at 15-18,000 feet, then 5 kms. (5000 metres) might be used.

If cloud is estimated at 18-21,000 feet, then 6 kms. (6000 metres) might be used.

The following table of average heights is given for guidance when estimating the height of cloud over Melbourne:—

Cloud Type	Height in Winter	Height in Summer
Ci	9 km.	10 km.
Cs	8-9 km.	9-10 km.
Cc	6-8 km.	7-8 km.
Ac	3-5 km.	3-6 km.
As	Variable	Variable
	2½-5 km.	2½-6 km.

4. Computation

(a) **P.B. Slide Rule.**—Having obtained azimuth and elevation bearings for successive time intervals, and having determined the cloud height, the method of computation is the same as for pilot balloon ascents except that the height is the same for each line of working and that each line is worked out only till the values of the components for V_{WE} and V_{SN} are obtained. These values are then averaged and compounded to give the mean direction and velocity.

An example is shown:—

Height metres	Time min.	Azimuth °	Elevation °	$\frac{\text{h cot E}}{60}$	DE	DN	V_{WE}	V_{SN}	Vel. km/hr	Direction °
5000	0	143·2	57·2	54	−32	+43				
5000	1	146·4	56·0	56	−31	+47	+1	+4·		
5000	2	150·1	54·2	60	−30	+52	+1	+5·		
		Mean Velocity and Direction					+1	+4.5	17	193

(b) **P.B. Circular Calculator.**—When using the P.B. circular calculator turn the calculator round so that the "metre scale" of heights can be used. The procedure then is given in the following steps:—

(i) Turn the protractor until the azimuth bearing is over the index line (elevation 0°).

(ii) Set the radial arm on the angle of elevation.

(iii) Project the point of intersection of the radial arm and the height line on to the index line.

(iv) These steps are repeated for each successive reading of azimuth and elevation bearing in mind that the same height line is used in each case.

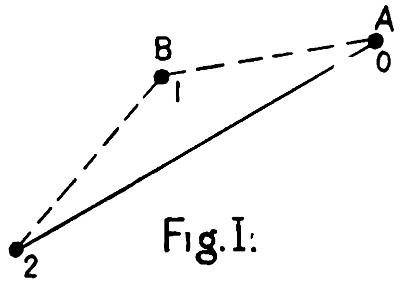


Fig. I:

(v) When the points have been plotted for each successive set of readings, JOIN THE FIRST POINT PLOTTED TO THE LAST POINT PLOTTED. This line gives the resultant direction and velocity of the lines joining each successive point.

In Fig. I, A, B and C give the plotted positions of three successive readings and the line AC is the resultant of AB and BC. In Fig. II A, B, C and D give the position of four successive readings and the line AD is the resultant of AB, BC and CD.

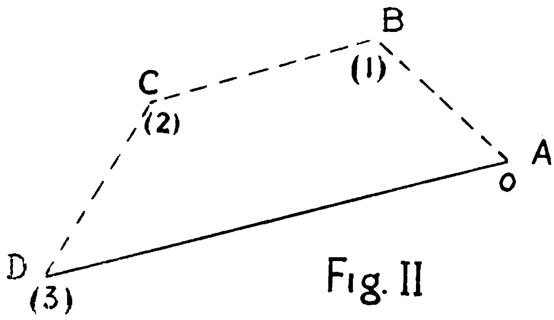


Fig. II

N.B.—Do not join the origin (centre of protractor) to the first point plotted.

(vi) Divide this line into the same number of parts as the number of time intervals. If **three** readings have been taken, then bisect the resultant line AC. If **four** readings have been taken, then trisect the resultant line AD.

(vii) The direction of the cloud movement is then obtained by turning the protractor until this line (AC or AD) is parallel to the index line and reading the azimuth. Be careful that the line reads from right to left, i.e., the first point should be on the right hand end of the line and the last point on the left hand end of the line.

(viii) The velocity is obtained by using the scale of velocities to measure the distance from the first point plotted to the first dividing point, e.g., from the first point plotted to the point of bisection or the first point of trisection.

(ix) These steps may be still further simplified by taking a number of readings at regular time intervals and plotting the first and last readings of azimuth and elevation. Then join these two points. By turning the protractor till the resultant line is parallel to the index line, the mean direction is obtained by reading the azimuth angle. The velocity may be obtained by using the scale of velocities to measure the length of this line (in km. per hour) and dividing the resulting velocity by the number of time intervals.

(x) N.B.—

(a) If the **half scale** has been used then the velocity must be doubled.

(b) If **half minute readings** have been taken then the resulting velocity must also be doubled.

5. **Reporting "Neph" Observations**

Meteorological assistants are instructed that observations of the speed and movement of middle and upper level clouds are to be made by the use of a P.B. theodolite at each observational hour, whenever possible.

Results of observations are to be entered in the field book and plotted in red on the upper wind chart.

The first "Neph" observations taken for the day will be included in the first available telegraphed observational report. Subsequent observations will not be telegraphed unless a decided change in direction and/or speed has been observed.

D. ESTIMATING THE REMOTENESS OF CLOUDS

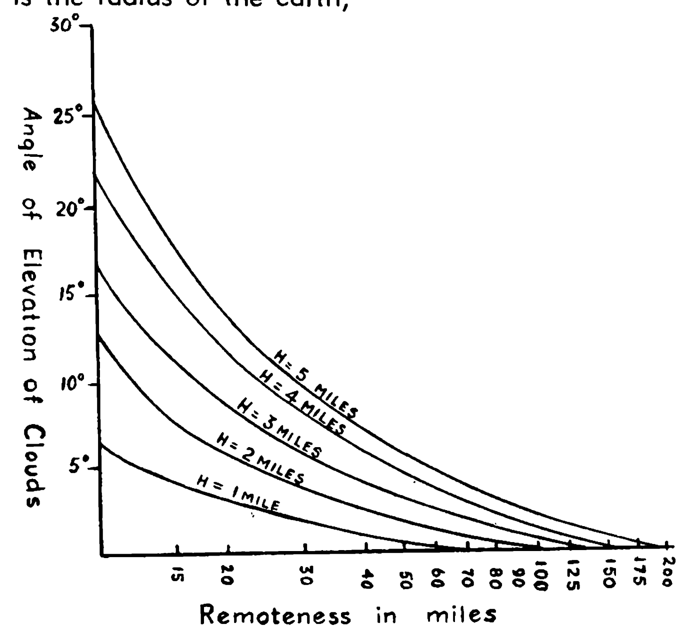
The approximate distance away of cloud elements, particularly those of high altitude, such as cirriform clouds, alto clouds, high Sc., large Cu., and Cb., may be found from the formula—

$$\tan E = \frac{2RH - D^2}{2RD}$$

where

E is the angle of elevation of the cloud feature, which may be measured with a P.B. theodolite from M.S.L.;

R is the radius of the earth;



H is the height of the cloud feature above M.S.L. to the nearest mile;

D is the horizontal distance away of the cloud feature in miles.

Lamb (Met. Mag. 1938) has constructed a set of curves on a semi-logarithmic scale of distance and elevation to give the horizontal distance of clouds at heights of 1, 2, 3, 4 and 5 miles.

These curves may be used at stations as high as 500 feet above M.S.L. because the error corresponding to this departure from sea level is never more than 5 miles.

Estimations of Height

The estimation of the height of distant cloud elements will be assisted by a knowledge of the average heights of cloud in the vicinity of a station at different times of the year. If these values are available in feet, they may be converted to miles by taking heights between 4000 and 7000 feet as being 1 mile,

heights	of	8,000			as	being	$1\frac{1}{2}$	miles.
„	between	9,000	and	11,000	„	„	2	„
„	„	12,000	„	13,000	„	„	$2\frac{1}{2}$	„
„	„	14,000	„	17,000	„	„	3	„
„	„	18,000	„	19,000	„	„	$3\frac{1}{2}$	„
„	„	20,000	„	23,000	„	„	4	„
„	of	24,000			„	„	$4\frac{1}{2}$	„
„	between	25,000	„	28,000	„	„	5	„

Thus, generally speaking,

Ci. or Cs. may be taken as being approximately at a height of 5 miles.

Cc. may be taken as being approximately at a height of $4\frac{1}{2}$ miles.

As. may be taken as being approximately at a height of 3 miles.

Ac. may be taken as being approximately at a height of 3 miles.

Estimations of the distance of "low" clouds (large Cu. or Cb., etc.) should not be attempted unless a reliable estimation may be made of the height of the **top** of the cloud, which is the point whose elevation should be measured. While the tops of Cb. may vary from 4 to 5 miles, those of large Cu. vary between 2 to 3 miles.

Use of Diagram

In order to determine the remoteness or distance away of a particular cloud element, it is necessary—

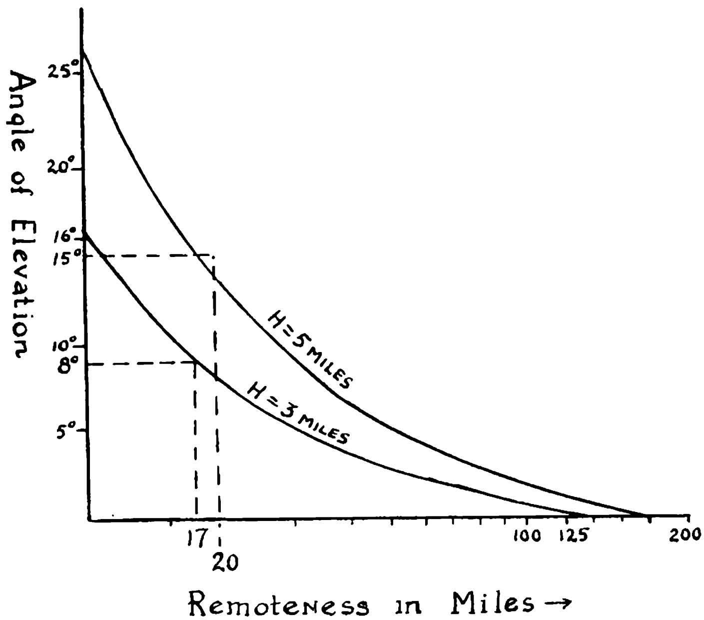
(a) to measure its angle of elevation by centering the cloud element on the graticule of a P.B. theodolite (which has been set up and levelled);

(b) to estimate the height of the cloud element to the nearest mile, and

(c) to draw a horizontal line on the diagram from the angle of elevation (on the vertical axis) to the curve corresponding to the height of the cloud element, and then to project this point of intersection on to the (horizontal) "distance scale," where the remoteness of the feature will be given in miles.

Example

If Ci. cloud were observed at an angle of elevation of 15° and the height were taken to be 5 miles, then the diagram shows the distance of the cloud element to be 20 miles. If Ac. cloud were observed at an angle of elevation of 8° and the height were taken to be 3 miles, the cloud element would be 17 miles away.



Application

Particularly if associated with nephoscope observations a knowledge of the remoteness of clouds will be a useful adjunct to other synoptic data by giving indications of—

(a) the rate of advance of warm and cold front clouds (if a number of successive observations are taken);

(b) the distance and location of thunderstorms or showers associated with large convectional cloud;

(c) the time of arrival of showers or thunderstorms associated with distant Cu. or Cb. moving towards a station; or

(d) the rate at which the sky may become overcast by the arrival of Ac. or (high) Sc.

SECTION 24

DOUBLE THEODOLITE OBSERVATIONS

1. GENERAL

Two theodolites are set up, one at each end of a measured base line and the balloon released from one of the observing stations. Some method of signalling must be used between the observing stations because simultaneous readings must be made with each theodolite. Usually a semaphore system is used, a flag being held up at "5 to go" and dropped at "time."

The balloon must not be abandoned at either station before disappearance unless the flight has been in progress for sufficient time to give all the required information. If it is lost at one station before the other then the fact should be signalled to the other station, so that if necessary the flight can then be calculated as a single theodolite ascent using the rate of ascent found from the double theodolite ascent.

2. THEODOLITE SETTING

The theodolites are levelled in the usual manner but not oriented to true north. The theodolite at the main station (called A) is set with 360° azimuth on the secondary station (called B). The theodolite at station B is set so that 180° azimuth is on station A. By this setting both instruments will read the same azimuth if pointing in the same direction along the base line. This simplifies calculations since the third angle of the base triangle is the difference between the two azimuth readings.

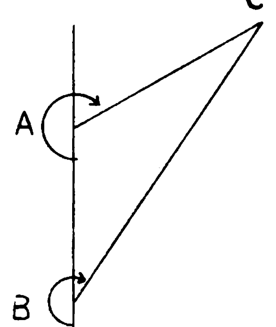
3. CALCULATIONS

At first we will assume the base line AB to be horizontal.

If A and B are the azimuth angles of balloon at theodolites A and B—

Then angle $C = A - B$

i.e., $AC = \dfrac{AB \sin B}{\sin C}$ $\quad BC = \dfrac{AB \sin A}{\sin C}$



AC is the horizontal distance travelled by the balloon in 1 minute, that is, h cot E of the normal calculations. To obtain the travel in 1 second, we must divide by 60 and thus—

$$\frac{AC}{60} = \frac{AB}{60} \frac{\sin B}{\sin C}$$

The following steps are necessary on the slide rule:—

(1) Set value of $\frac{AB}{60}$ on end of arc on scale A.

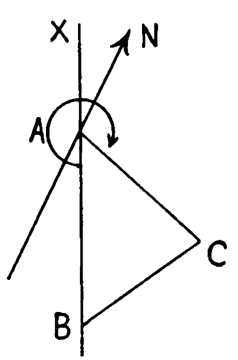
(2) Read value on scale B coinciding with angle B on sin scale A. (If B is between 90°-180° or 270°-360°, read cos B for sine B.)

(3) Slide scale B until this value coincides with angle C on sin scale A.

(4) Read off value of $\frac{AB}{60} \frac{\sin B}{\sin C}$ at end of arc of scale A.

The velocity of the balloon may be calculated from data giving successive positions of the point C in terms of **either** of the sides AC or BC and the **true** bearing of point C.

The true bearing of A from B is found by a compass or from known reference objects, then if this angle is added to the azimuth readings of theodolites, the true bearing of the balloon plus 180° is obtained, which is required for the calculations.



The azimuth reading of C from A is the reflex angle B.A.C.

The true bearing of A from B is reflex angle NAX (later referred to as K), so that the true bearing of C is acute angle NAC, which equals the obtuse angle NAB-acute angle BAC.

The obtuse angle NAB = reflex angle NAX-180°.

The acute angle BAC = 360°-reflex angle BAC.

i.e., bearing of C from A = (bearing of A from B-180) minus (360-azimuth of balloon).

Take as example the case where azimuth bearing of balloon from A is 275° and true bearing of A from B is 340°, then true bearing of C from A is (340 — 180) — (360 — 275)°, i.e., 75°.

If bearing of balloon from B is 231°, then true bearing of balloon from B is (340 — 180) — (360 — 231)°, i.e., 31°.

But as we need the true bearing plus 180° in order to get the direction from which the wind is blowing, all we have to do is to add the azimuth reading and the bearing of A from B, subtracting 360° if necessary. The reason for this is obvious from the above relations.

To calculate the velocity and direction of wind, the horizontal travel of the balloon must be resolved into East and North components as for an ordinary flight. The usual sign convention is used. The increments in the components are obtained in the usual way and compounded to obtain the wind velocity and direction.

The only difference in the calculation at the out station from that at the main station is the resolving of the base line AB into East and North components and then proceeding as for the main station.

The East component of base line is AB sin $(B + K)$.

The North component of base line is AB cos $(B + K)$.

The East component of Point C from A is AC sin $(A + K)$.

The East component of Point C from B is BC sin $(B + K)$.

The North component of Point C from A is AC cos $(A + K)$.

The North component of Point C from B is BC cos $(B + K)$.

To calculate the height of the balloon, the vertical triangle APC or BPC must be solved (P is position of balloon and is vertically above C).

If h_a = height of balloon above station A at elevation E_a then $h_a = AC \tan e_a$. From station B, $h_b = BC \tan e_b$.

The value of h_a is obtained as follows on the slide rule:—

(1) Set value of $\dfrac{AC}{60}$ on mark H.

(2) Set cursor on tan scale to read e_a.

(3) Read value of h_a from this cursor—watch position of the decimal point. (The reading opposite end of arc is 60 times the value opposite mark H.)

The H_a of the pro forma sheet is the height of the station A above mean sea level plus h_a. This is to allow for the possibility of the two stations not being in the same horizontal plane.

The various columns on the pro forma are self explanatory. The column headed 90-E_a need not be filled in as the method given for finding h_a does not use this angle. On pro forma A, H_b is obtained from pro forma B. $H_a = h_a +$ height of station above sea level.

On pro form B it will be noticed that the first line is numbered 0 in order to get the co-ordinates of station A to obtain the initial values of E_b and N_b which are necessary since the balloon is released at station A. The velocity is in metres per second and the height in metres.

The top of pro forma B is the same as pro forma A, except in the equations a suffix b replaces the a, and the angles A and B interchanged in the equations. To enable both pro formas to fit on one sheet, the top of pro forma B is omitted.

4. METHODS OF PREPARING AZIMUTH ANGLES

It will be noticed that the azimuth angles are used in the formula instead of the smaller interior angles A and B, of the horizontal triangle. With a little practice, and by taking advantage of the following trigonometric relations, the larger angles are readily set on the slide rule:—Angles from 0° to 90° are considered as x; from 90° to 180° as $90° + x$; from 180° to 270° as $180° + x$; and from 270° to 360° as $270° + x$. Therefore, $\sin(90° + x) = \cos x$; $\sin(180° + x) = \sin x$; $\sin(270° + x) = -\cos x$. That is, to obtain the sine of angles between 90° and 180°, subtract 90° and use the cosine of the result; between 180° and 270°, subtract 180° and use the sine, and between 270° and 360°, subtract 270° and use the cosine. This device is employed to avoid the tedious process of subtracting the angles from 180° and 360°, as would otherwise be necessary. The signs are automatically taken care of in the calculations.

By substituting the first two digits of the azimuth angles by their sum, the mechanical process of the above subtraction is eliminated and the required angle is obtained at a glance. For example, in angle 113·3°, substitute 2 for 11, the result, 23·3°, is the angle required; hence $\sin 113{\cdot}3° = \cos 23{\cdot}3°$ in angle 213·1°, substitute 3 for 21, hence $\sin 213{\cdot}1° = \sin 33{\cdot}1°$; and, in angle 347·4°, substitute 7 for 34, hence $\sin 347{\cdot}4° = \cos 77{\cdot}4°$.

This device holds true except for angles just above 90°, 180° and 270°, where the subtraction is made without mental effort. Moreover, when the sum of the first two digits of the angle is 10 or 11 a second addition of these digits must be made, i.e., use 1 or 2 respectively.

Obviously, the methods used in preparing the angles for slide rule are great time savers in computation. The only mechanical work required is in obtaining A — B, and this subtraction is done for the entire observation in advance of the computation.

TWO THEODOLITE METHOD. PILOT BALLOON ASCENT No. 15. CALCULATIONS—STATION A.

Station	Description	Co-ordinates East	Co-ordinates North	Ht. above M.S.L.
A (Set 360°)	Meteorological Bureau			50 m.
B (Set 180°)	Government House	−13.8	+38.5	70 m.

Balloon released at A. Base AB = 2450 metres. $\frac{AB}{60} = 40.8$ metres.

True bearing of A from B = K = 340.2°

$AC = \frac{AB \sin B}{\sin C}$. $C = A - B$

$E_a = AC \sin (A + K)$.

$N_a = AC \cos (A + K)$.

Balloon Data:

Weight . . . . 80 Grams.
Free Lift . . . . 552 Grams
Assumed Rate of Ascent 300 metres per minute
Reason For Loss: Cloud

No.	Home Station A	Home Station e_a	Out Station B	Out Station e_b	C	$\frac{AC}{60}$	A + K	$\frac{E_a}{60}$	$\frac{N_a}{60}$	V_E	V_N	Vel. per min.	Direction	$h_a = AC \tan e_a$	$H_a = h_a + 50$	H_b	Average Heights	Rate of Ascent
1	282.2	33.9	192.9	8.2	89.3	9.1	262.4	+9.0	+1.2	+9.0	+1.2	9.1	263	367	417	414	415	365
2	280.6	33.5	205.3	15.5	75.3	18.1	260.8	+17.8	+2.9	+8.8	+1.7	8.9	259	719	769	759	764	349
3	280.3	34.1	215.7	21.4	64.6	26.3	260.5	+25.8	+4.3	+8.0	+1.4	8.1	260	1070	1120	1118	1119	355
4	277.8	33.8	224.3	24.9	53.5	35.6	258.0	+34.8	+7.4	+9.0	+3.1	9.5	251	1435	1485	1480	1482	363
5	275.0	33.9	231.3	27.0	43.7	46.1	255.2	+44.6	+11.8	+9.8	+4.4	10.7	246	1860	1910	1870	1890	408
6	273.6	34.1	235.3	28.8	38.3	54.2	253.8	+52.0	+15.1	+7.4	+3.3	8.3	246	2200	2250	2250	2250	360

Calculations Station B

No.	A	e_a	B	e_b	C	$\frac{BC}{60}$	B + K	$\frac{E_b}{60}$	$\frac{N_b}{60}$	V_E	V_N	Vel. per min.	Direction	$h_b = BC \tan e_b$	$H_b = h_b + 70$	H_a
*0	360.0	+0.5	180.0	−0.5	180.0	40.8	160.2	−13.8	+38.5	—	—	—	—	−20	—	—
*1	282.2	33.9	192.9	8.2	89.3	39.9	173.1	−4.8	+39.6	+9.0	+1.1	9.1	263	344	414	417
2	280.6	33.5	205.3	15.5	75.3	41.4	185.7	+4.1	+41.2	+8.7	+1.6	8.8	260	689	759	769
3	280.3	34.1	215.7	21.4	64.6	44.4	195.9	+12.2	+42.8	+8.1	+1.6	8.2	259	1048	1118	1120
4	277.8	33.8	224.3	24.9	53.5	50.4	204.5	+20.8	+45.8	+8.6	+3.0	9.2	251	1410	1480	1485
5	275.0	33.9	231.3	27.0	43.7	58.9	211.5	+30.8	+50.2	+10.0	+4.4	10.8	246	1800	1870	1910
6	273.6	34.1	235.3	28.8	38.3	65.8	215.5	+38.2	+53.5	+7.4	+3.3	8.3	246	2180	2250	2300

*See Section 4 regarding azimuth angles.

SECTION 25

OPTICAL PHENOMENA IN THE ATMOSPHERE

Optical phenomena are extremely numerous and varied. Some are of striking beauty. Some are important in that they convey valuable information, as they are more or less closely associated with the weather. Observation of optical phenomena may assist observations of meteorological elements, e.g., the existence of halos or coronæ will help in distinguishing cloud types.

1. HALO PHENOMENA

The term **halo** denotes a circle of light round a luminous body, e.g., the sun or moon, and is formed by the reflection and refraction of light by ice crystals. Although there are many different kinds of halos the most common is a luminous ring of 22° radius around the sun or moon. The space within the ring appears less bright than that just outside. If faint the ring is white; if more developed the inner edge is a faint red, outside which yellow may be detected. The angle of 22° is the angle of minimum deviation for light passing through a prism of ice with faces inclined at 60°. Alternate faces of a hexagonal prism are inclined at this angle, and as hexagonal prisms are frequently found amongst the ice crystals of which cirrus clouds are composed, the halo is probably due to the refraction of light through such prisms.

A halo of 46° occurs more rarely. Its luminosity is usually much less than that of the halo of 22°. It requires crystals with faces inclined at right angles.

Mock Sun Ring.—The "parhelic circle" in "mock sun ring" is a colourless white ring, which passes through the sun parallel to the horizon.

Mock Sun.—The parhelion or "mock sun" is the luminous image of the sun seen most frequently at or near the intersection of the halo of 22° with the mock sun ring. While occasionally they may be brilliantly coloured, with red on the side nearest the sun, and yellow, green and blue, following in order, at other times they may appear without any rings. This phenomena requires prismatic ice crystals with their axes vertical.

Mock Moons.—These are analogous to mock suns.

Sun Pillars.—A sun pillar is a vertical column of light above (sometimes below) the sun, most easily observed during cold weather at sunrise or sunset. They frequently extend about 20° above the sun, and generally end in a point. At sunset, they may

be entirely red, but generally they are white and show a marked glittering. The phenomena, which is due to the reflection of sunlight from small snow crystals, may be seen over a wide area.

2. CORONÆ

The corona is a series of coloured rings around the sun or moon. The space immediately adjacent to the luminary is a bluish white, while this region is bounded on the outside by a brownish-red ring, these two together forming the so-called "aureole." Generally the aureole alone appears, but a complete corona has a set of coloured rings surrounding the aureole, violet inside followed by blue, green, yellow to red on the outside. The series may be repeated more than once, but the colours are usually represented merely by greenish and pinkish tints.

They are due to difraction of the light by water drops. If the colours are pure it is an indication that the drops are uniform in size. The radius of the corona is inversely proportional to the size of the droplets. Thus, a corona, whose size is increasing, indicates that the water particles are diminishing in size.

A corona is distinguished from a halo in that the colour sequence is opposite, the red of the halo being inside, that of the corona on the outside. While the red of the halo is followed by orange, yellow and green the brownish-red of the aureole is followed by violet to red. Also they differ from halos in having smaller (except in rare cases) and variable radii.

Bishop's Ring.—This is a dull reddish-brown ring which is seen at certain periods round the sun in a clear sky. In the middle of the day the inner radius of the ring is about 10°, the outer 20°, but when the sun is low the ring becomes larger; the brightest part is about 19° from the sun. After sunset the ring is lost in the warm colours of the sky.

3. IRIDESCENCE OR IRISATION

Iridescence refers to tinted patches generally of a delicate red or green, sometimes blue and yellow, occasionally seen on the edges of alto-cumulus clouds, at a distance up to 25° or more from the sun or moon. The boundaries of the tints are not circles with the sun as centre but tend to occur in bands following the outlines of the cloud. The iridescence is probably due to difraction by small waterdrops and the colours seen are determined partly by distance from the sun, partly by the size of the drops. The arrangement of the colours is due to the regular gradual variation in the size of the drops, the large drops occurring in the central parts and the smaller drops at the edges of the cloud. The drops responsible for iridescence are very small and probably supercooled well below freezing level.

4. RAINBOWS

Rainbows are due to the refraction and reflection of sunlight in falling drops of rain. The ordinary rainbow is a group of circular, or nearly circular, arcs of colours whose common centre is on the line connecting the observer's eye with the exciting light (sun, moon, electric arc, etc.) or rather, except rarely, on that line extended in the direction of the observer's shadow.

A great number of rainbows are theoretically possible. The most brilliant bow is the **primary bow,** which shows the sequence of colours, violet, blue, green, yellow, orange and red, the red being on the outside or top of the bow. The outer border of about 42° radius appears opposite to the sun. The primary bow is formed by means of the reflection of sunlight from the far side of each raindrop. The light which is reflected in this way does not come out in all directions but only in directions lying within about 42° from the direction of the sun. The reflected light is most intense near the limit. Accordingly an observer looking towards the raindrops receives a certain amount of light from all directions within 42° from the shadow of his head, but most light along rays which make an angle of about 42° with the central line. The limiting angle depends on the colour of the light, and in so much as white light is compounded of light of different spectral colours, the observer sees the concentric arches of different colours.

Some of the light falling on a drop does not emerge until after it has been reflected twice. None of the twice reflected light which reaches an observer makes an angle of less than 50° with the line to the centre of his shadow. This is the explanation of the **secondary bow.** It is the next brightest bow to that of the primary and is on the same side of the observer but the order of the colours is reversed.

The third, or **tertiary bow,** having about the same radius as that of the primary, and colour in the same order, lies between the observer and the sun, but is so faint that it is rarely seen in nature. The space between the inner and outer bows appears darker than the space inside the inner and beyond the outer bow.

Along the inner side of the primary bow and the outer side of the secondary bow often appear supernumerary bows. They are parallel to the primary and secondary bows and appear as rather narrow bands of colour, essentially red, or red and green. They differ greatly in purity and colour, number visible, width, etc., not only between individual bows but, also, between the several parts of the same bow. No such coloured arcs, however, occur between the principal bows.

The common centre of the primary and secondary bow is, angularly, as far below the observer as the source (sun generally) is above, so that, usually, less than a semi-circle of these spectral arcs is visible and never more, except from an eminence. Also it

might be noted that if the sun's altitude exceeds 42° no primary rainbow can be formed, consequently rainbows are mainly morning and evening phenomena.

Records show that rainbows vary from one another. Colours vary, width of bands of colours vary, total width varies, while the purity and brightness of the different colours are subject to large variations. These differences depend on the size of the drops. Drops larger than 1 mm. in diameter yield brilliant bows about 2° in width; the limiting colour is distinctly red. With drops about 0·3 mm. in diameter the limiting colour is orange. With smaller drops supernumerary bows appear to be separate from the primary bow. With still smaller drops about ·05 mm. in diameter the rainbow degenerates into a white fog bow with faint traces of colour at the edges.

Rainbows are not infrequently observed by moonlight, but as the human eye cannot distinguish colour with faint lights the lunar rainbow appears to be white.

5. CREPUSCULAR RAYS

When dust and smoke accumulate in the atmosphere crepuscular rays frequently are seen in the atmosphere. The phenomenon is due to the illumination of the dust particles by sunlight. When the sun is low, the shadows of clouds or mountain ridges will be thrown right across the sky, and as the particles in the shadow are much darker than those in the sunlight, the course of the shadow can be traced for varying distances. A series of alternately light and dark bands are thus produced. The bands are really parallel, but the effect of perspective is to make them appear to diverge from the sun. Crepuscular rays are seen best just after sunrise. They are sometimes referred to as "the sun drawing water."

6. THE GREEN RAY OR FLASH

The very last glimpse of the sun as it is setting is sometimes of a very brilliant green. The colour is due to the unequal refraction of light of different colours—the blue and green more than the yellow and red. The colour lasts but a few seconds. It requires a clear atmosphere.

7. SUNRISE AND SUNSET COLOURS

When light waves meet obstacles in their path, the waves are broken and secondary waves proceed in all directions from the obstacles. The direct light is therefore reduced in strength and the further the light goes through the atmosphere containing such obstacles the more the strength is reduced, the energy being used up in producing scattered light. This effect is more pronounced with blue light for which the wave length is short than with red light

for which the wave length is longer. Accordingly a beam of white light passing through air loses the constituents of shorter wave-length and becomes yellow, then orange and finally red. This accounts for the changing colour of the sun as it nears the horizon.

8. ZODIACAL LIGHT

This is caused by an accumulation of matter in a state of very great tenuity centred round the sun and rotating with it. The luminosity is probably due to the scattering of sunlight by an exceedingly rare gas which is rotating round the sun like an extended atmosphere. It has the appearance of a pale diffused light extending from the sun back along the direction the latter has moved from, after sunset, or forward in its direction of motion before sunrise. It is prominent in the northern interior of Australia, comparable almost in brilliance with the Milky Way.

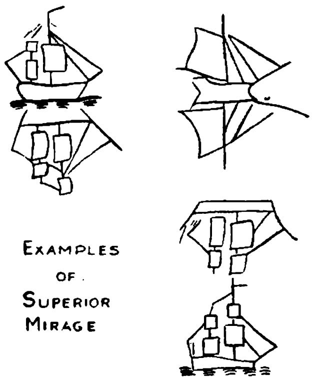
9. MIRAGE

The appearance and positions of distant objects are always altered to some extent by the refraction of the light which, passing from the object to the observer, has to traverse obliquely layers of air of different density, and sometimes the displacement of position or distortion of appearance is so great as to produce an illusion of apparent water, trees, buildings, etc. Such phenomena are conspicuous when the variations of temperature close to the ground are very marked. Over a heated desert the air very close to the ground is less dense than that above it, so that the velocity of light is greatest close to the ground. Rays coming down from the sky at a gentle inclination may be bent up again to the observer, to whom the rays appear to come from a bright water surface.

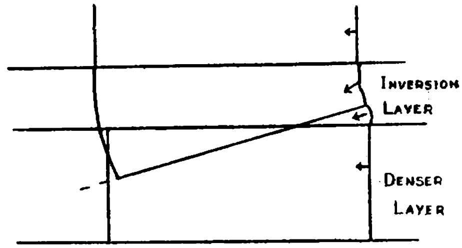
The **superior mirage** occurs when the light rays are bent downward from a warm stratum of air resting on a colder air stratum. One or more images of a distant object may occasionally be seen above it. The image nearest the object is always inverted, and appears as though reflected from an overhead plane mirror.

The **inferior mirage** ocurs over approximately level places and, there only, when they are so strongly heated that for a short distance the density of the atmosphere increases with elevation. The surface air is in unstable equilibrium and rising in innumerable filaments, but its rarefied state is maintained so long as there is an abundant supply of insolation. It is common in flat desert regions during the warmer hours of the day when apparently mirrored images may appear below distant objects and somewhat separated from them. The phenomenon closely simulates, even to the quivering of the images, the reflection, by a quiet body of water, of objects on the distant shore.

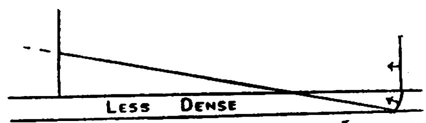
Lateral images are produced by vertical sheets of abnormally dense, or abnormally rare, atmosphere. The images then do not appear exactly in the same vertical.



Examples of Superior Mirage



Wave Fronts Giving a Superior Mirage



Wave Fronts Giving an Inferior Mirage

10. AURORA

The aurora is a well known but imperfectly understood luminous phenomenon of the upper atmosphere. The aurora takes many forms; several types have been recognised, such as arcs, bands, rays, curtains or draperies, coronas, luminous patches, and diffuse glows—the most important being that of an arc and that of a curtain. Many auroras are quiescent, others exceedingly changeable, flittering from side to side like wandering searchlights, and, in some cases, even waving like giant tongues of flame. The quiet arc is the most symmetrical and stable form; sometimes persisting with little visible variation for hours; frequently, however, streams of light shoot out radially from the arc and the whole structure undergoes rapid change. The lower edge, both of arcs and curtains, is usually much the better defined.

Many auroras are practically white. Red, yellow, and green are also common aurora colours. Some streaks and bands are reddish through their lower portion, then yellowish, and finally greenish through their higher portions. Much of the light is due to nitrogen bands, none to hydrogen lines, while the "Auroral line," the brightest of all, is due to oxygen, presumably in a special state, and probably is intensified by the presence of helium.

The upper limits of the auroral light vary from about 100 to over 300 kms., and the lower limits from, perhaps, 85 to 170 kms., with two well defined maxima, one at 100 kms., the other at 106 kms.

On the average, auroras are more numerous during years of sun spot maxima than during years of spot minima. They also appear to be more numerous before midnight than after. It is

practically certain that they are due to electric discharges and that as they vary in frequency with the sun spot period, it would appear that this current either comes from or is induced by the sun. They are frequently accompanied by magnetic storms.

Australia is without the latitudes in which the aurora is seen at all frequently, but on exceptional occasions it is seen within 30° of the equator. The "Aurora Australis," or southern aurora, when seen in Australia, generally takes the form of a pinkish glow to the southwards. At times, however, an arch of light is seen over the southern horizon, from which streamers may play towards the zenith. Occasionally the streamers may appear bluish or greenish in colour.

11. LIGHTNING

This is the flash of a discharge of electricity between two clouds or between a cloud and the earth. A distinction is drawn between "forked" lightning, in which the path of the actual discharge is visible, and "sheet" lightning, in which all that is seen is the flash of illuminated clouds and which is attributable to the light of a discharge of which the actual path is not visible.

A. Matthias found that a single lightning flash usually involved about five partial discharges. The duration of a partial discharge was between ·0005 second and ·01 second. The maximum interval between consecutive partial discharges was 0·37 second. Photographs reveal that a flash begins with a faint light travelling down from the cloud in a jerky way and leaving a fainter trail. At intervals the trail branches, the light travelling simultaneously along different tracks. Eventually one of the branches approaches the earth. Then a vigorous, much brighter, luminosity travels rapidly up this branch, and the other branches light up in succession. Subsequent strokes are not branched, but they have the same double character, leader and return stroke. The time taken by the leader to reach the ground is comparable with ·01 second, the return stroke covers the same distance in about ·0001 second.

Et. Elmo's Fire.—This is a brush-like discharge of electricity sometimes seen on the masts and yards of ships at sea during stormy weather; it is also seen on mountains on projecting objects. According to Trabert, St. Elmo's Fire changes with the sign of the electricity which is being discharged into the air. The negative "fire" is concentrated so that an object like a mast is completely enveloped in fire. The positive fire takes the form of streamers some three or four inches long.

Ball Lightning.—It consists of a glowing ball of incandescent matter usually associated with a lightning flash. Sometimes the ball will explode with varying degrees of violence. Its movements are often quite leisurely and eratic. The matter composing it appears to have been activated in some way by the electrical energy of the lightning discharge.

SECTION 26

SOUND RANGING

(See Handbook of Meteorological Co-operation with Sound Ranging Units.)

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course
for
Meteorological Assistants

PART 2

Instrumental Meteorology

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course
for
Meteorological Assistants

PART 2

Instrumental Meteorology

INSTRUMENTAL METEOROLOGY

Meteorological Instruments are now catalogued in R.A.A.F. publication No. 2—Vocabulary of Stores—Group G., Section 268, Meteorological Stores.

Wherever possible the vocabulary number is given to familiarise Meteorological Trainees with the system.

When any instruments or replacements are required, it is essential that they be ordered by "Ident. Number" specifying also the quantity required.

For example, if 2 doz. 48" balloons (20 gm.), (red) 200 cub. ft. of hydrogen, 1 balloon filler, 1 theodolite and tripod, were required, the order would be made out:—

G.268/5018	Balloons, 48 inch (Red) ..	24
G.268/482	Gas, hydrogen	200 cub. ft.
G.268/5092	Fillers, balloon	1
G.268/5148	Theodolite, Mk. I	1
G.268/5117	Mounting Field, for above ..	1

INSTRUMENTAL METEOROLOGY

TYPES OF THERMOMETERS

SECTION 1

DEVELOPMENT OF LIQUID THERMOMETERS

The thermometer appears to have been first used at the beginning of the seventeenth century, but the identity of the inventor is rather obscure. In one type the scale was so chosen as to record 20° for the coldest temperature experienced in winter and 80° for the hottest at mid-summer. Boyle first suggested the use of fixed points and chose a freezing point of distilled water as zero. Fahrenheit chose as his zero the lowest temperature he could obtain for the mixture of ice, water, and salt. The temperature of ice and water he called 32°, and the normal temperature of the human body 96°. Fahrenheit observed that on his scale the boiling point of water was 212°. The numbers 32 and 212 are retained to the present day for the freezing and boiling points of water on the Fahrenheit scale, although the modern Fahrenheit scale is not exactly the same as the original. More accurate observations show that the temperature of the human body is 98·4° instead of 96°.

The Centigrade scale was chosen by Celsius, who divided the interval between the freezing and boiling points of water into 100°. He, however, designated freezing point by 100 and boiling point by 0. Shortly after this was reversed, producing the modern Centigrade scale.

THERMOMETERS IN USE

1. **Standard or Reference Thermometer** (G 268/5161)

An ordinary mercury in glass thermometer mounted on a porcelain scale graduated from 0° to 140° Fahrenheit.

2. **Maximum Thermometer** (G 268/5160)

For recording maximum temperatures, we use a mercurial thermometer, in which there is a fine constriction at a point in the bore of the stem, just above the bulb which offers considerably more resistance to the flow of mercury than the remainder of the bore. The thermometer is mounted in a wooden shield and has not a porcelain scale.

When the temperature is rising the mercury is forced past the constriction and the end of the column indicates correctly the prevailing temperature, but when the temperature falls the mercury column breaks at the constriction as soon as the mercury

in the bulb contracts, and the further end of the column remains at a point corresponding with the highest temperature attained. If the mercury is not retained in the upper end of the capillary by the constriction, then the thermometer should be replaced. The constriction often becomes worn by the action of the mercury against the glass when resetting the thermometer. The thermometer, therefore, always indicates the highest temperature to which it has been subjected since it was last "set." "Setting" the thermometer is performed by shaking back the mercury until the column is continuous. It is usual to support the thermometer in a nearly horizontal position with a slight slope downwards towards the bulb.

3. **Minimum Thermometer** (G 268/5162)

For recording minimum temperatures, a spirit thermometer is used, whose range is from 0° F. to 140° F. Inserted in the bore is an index in the form of a long dumb-bell of dark glass or steel, which is normally completely immersed in the alcohol. The tube is supported horizontally and the flow of alcohol produced by a rise of temperature passes the index without moving it. Likewise the return of the alcohol towards the bulb due to the fall of temperature has no effect upon the index until the end of the column reaches the end of the index when, because of the surface tension at the free surface of the alcohol, any further decrease of temperature results in the withdrawal of the index towards the bulb, the further end being always at the end of the alcohol column, so long as the temperature continues to fall. The chief defect of the minimum thermometer is the fact that the alcohol tends to evaporate from its free surface and condenses at the further end of the bore where it may form a bubble. This may be removed by hitting the bulb of the thermometer against the palm of the hand or swinging the thermometer through the air with bulb outwards.

The G.P.E. or greatest permissible error of maximum and minimum thermometers is $\pm$ 0·2° F. Liquid-in-glass thermometers have been made self-recording by photographic means but this is rather incomplete.

4 **Mercury and steel thermometer** (G 268/5170)

In cases where it is desired to have a distant indication of the temperature, the mercury-in-glass thermometer is not suitable. The mercury and steel thermometer consists of a bulb, fine capillary tubing and a Bourdon gauge. The bulb and capillary tubing are all made of steel and are filled with mercury at an extremely high pressure (of the order of 120 atmospheres). The tubing enables the temperature to be indicated some distance away from the actual bulb of the thermometer. For example, the bulb of the thermometer may be mounted on the wing of a plane and the dial situated in the cockpit.

On heating the bulb of the thermometer, the greater expansion of the mercury contained in it causes it to flow through the capillary to the Bourdon tube, which, to accommodate an increased volume of mercury, undergoes an increase in its sectional area, the tube assuming, to a small extent, a less flattened form, an alteration which in turn causes it to unwind.

Owing to the special formation of the tube, the pointer would thus be caused to rotate truly about its axis, even if there were no bearings for its spindle. Actually bearings are provided so that the pointer will be steady under vibration, but as there is little or no load on them, there is no appreciable friction, and no error due to backlash.

The control afforded by this form of tube is much greater than that usually found in dial thermometers; it is unnecessary, for instance, to tap the indicator to obtain an accurate reading.

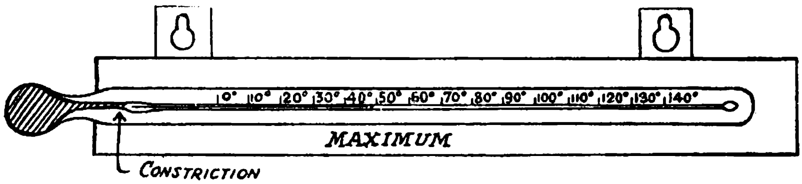
A further advantage is that, owing to no part of the movement being out of balance, there is no position error, or error due to an acceleration of the instrument in any direction.

In average installations the error arising from a difference in level between the bulb and the indicator is quite negligible, and in no case exceeds 0·05% of the range per foot difference. It will be realised that as the thermometers are filled with mercury under a pressure sometimes reaching 2,000 lbs. per square inch the extra pressure in any part due to a head of a few feet of mercury can have no appreciable effect.

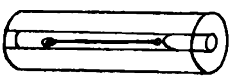
The instrument can be made recording by substituting a pen and chart for the dial gauge. If the capillary tubing exceeds 30′, the expansion of the volume of the mercury in the capillary becomes appreciable and the temperature of the capillary will affect readings and so a compensating link is inserted which takes up the change in the volume of mercury in the tubing. This type of thermometer cannot be dismantled.

5. **The Bi-Metallic Thermometer**

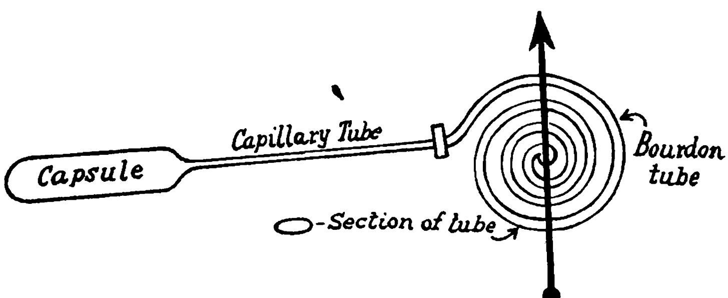
The bi-metallic thermometer can be used as an indicator or a recorder and is essentially a long strip consisting of two pieces of metal, copper and invar, electrically welded together and coiled in the form of a spiral, the invar being on the outside. One end of the coil is fixed and the other is connected to a pen arm or dial. Changes in temperature produce different expansions in the two metals, causing the spiral to close up or open out according as the temperature falls or rises. This movement is then communicated to the dial. Most "table" thermometers are of this type. The range of the instrument is varied by using more or less of the spiral and the zero by shifting the spiral bodily.



MAXIMUM THERMOMETER



INDEX IN MINIMUM THERMOMETER.



Schematic diagram of Mercury in Steel Thermometer

SECTION 2

MEASUREMENT OF AIR TEMPERATURE

The accurate measurement of air temperature in the open is one of the most difficult of all meteorological measurements, for it is so readily affected by radiation. Radiation from the sun, clouds, sky, the ground and surrounding objects passes in straight lines through the air without appreciably affecting its temperature, for air is very transparent to radiant heat, especially if it is dry; but for the measurement of air temperature we have to use some form of thermometer, which itself will absorb radiation, and we really measure the temperature of the active element which is in general at a different temperature from that of the air. These differences depend partly upon the nature of the thermometer, partly upon the nature of the radiation and partly upon the wind velocity and other factors.

Thermometer Screen

It is more usual, however, to provide some form of thermometer shelter or screen, which will serve the dual purpose of protecting the thermometers from damage and at the same time shield them from radiation. An ideal screen must satisfy the following conditions:—

(1) It must be a "uniform temperature enclosure";

(2) The temperature of the inner wall of the "enclosure" should be the same as that of the external air.

(3) The "enclosure" should completely surround the thermometers;

(4) The "enclosure" should be impervious to radiant heat.

Then the temperature of a thermometer would be the same as that of the inner walls, and, therefore, the same as that of the external air. Of these conditions the third and fourth are easiest to obtain; but the first and second are rather more difficult and can only be approximately realised by—

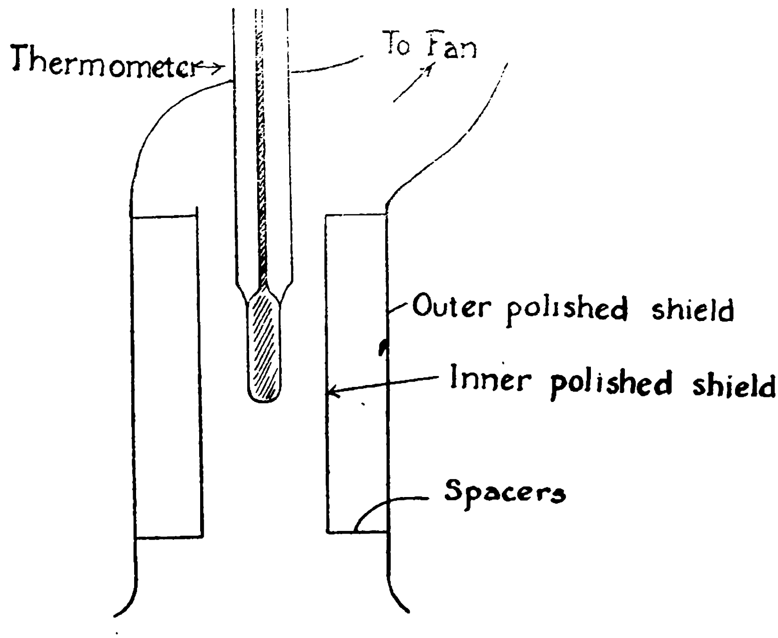
(a) Constructing the screen of a non-conducting material, e.g., wood;

(b) Providing the screen with double louvred walls with ample air circulating around them. The louvres tend to create slight eddy motion and give a better air flow in the screen for the measurement of wet bulb temperatures.

The type of screen known as the Stevenson Standard Screen (G268/5142) is described in the A.O.H., page 31. This type of screen gives extreme errors of $\pm 5°$ F.

Assman's Thermometer

This consists of a thermometer placed inside two concentric thin metal tubes, highly polished. A current of air is drawn by a fan through the inner tube and past the thermometer bulb, the velocity of the current being not less than two metres per second. Such an arrangement is practically impervious to radiation and can, therefore, be used in sunlight. But it is desirable to avoid unnecessary exposure to direct sunshine. This instrument gives a very high accuracy for air temperatures and is used largely in America. The Assman screening device with electrical resistance thermometers instead of mercury thermometers is used for distant indicating and recording purposes.



Assman Screen for Thermometer

Assman Psychrometer (G 268/5125)

This consists of two thermometers with Assman shields, mounted side by side, and connected to a common tube so that a single fan can ventilate both thermometers. The fan may be driven electrically or by clockwork. The bulb of one thermometer is covered with a cotton sock, which may be wet without removing the screen by using a special syringe. Care must be taken not to force water through the air passage onto the dry bulb thermometer.

Whirling Thermometers (G 268/5123)

The Australian pattern whirling thermometer consists of two thermometers mounted side by side on a metal frame, which has a revolving handle enabling it to be whirled. The thermometer is whirled for two minutes, stopped and read rapidly and whirled again, stopped and read. If the two readings are not the same, the whirling is repeated until consecutive readings are the same. When reading thermometers take care not to breathe on them.

It will be noticed that one thermometer is mounted so that the top of the bulb is on a level with the bottom of the other one. This is to enable the instrument to be used as a psychrometer. The lower thermometer bulb is fitted with a sock, which is a piece (usually 1½ inches) cut off a specially woven cotton tube which will fit any meteorological mercury thermometer bulb.

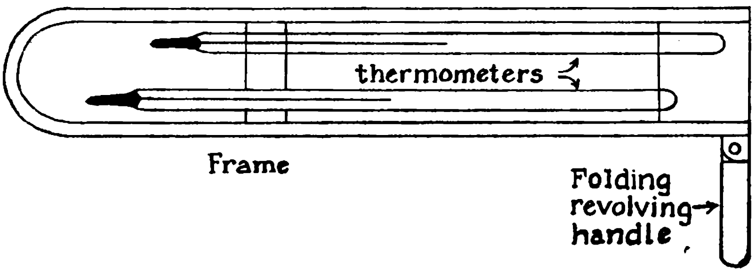
The sock can be wet with a special syringe, or by placing the lower part of the instrument in a vessel of water, being careful not to wet the bulb of the other thermometer and also to dry the frame after removal from the water.

When the handle is folded, the instrument will fit in the case provided for its carrying and protection. When folding or opening the handle, care must be taken to grasp the frame and handle and not the thermometers, otherwise a thermometer is liable to be broken. An occasional drop of oil at each end of the rotating handle will ensure its free working.

To replace a broken thermometer, remove the two screws on each clip holding the broken thermometer. This enables the broken thermometer to be removed and replaced by a spare. When replacing the thermometer see that the small projection on the top of the thermometer is placed in the hole on the frame, otherwise the thermometer will not be correctly held in place and may slip out.

If only the thread in a mercury thermometer is broken, the thermometer can be made serviceable again by heating the bulb until the threads join. Holding the bulb in the fingers will often provide sufficient heating, but, if not, gently wave a burning match about two inches below the bulb. No damage will result, because a small reservoir at the top of the capillary tube allows for over-heating. When the thread joins, stand the thermometer vertically until cool. Bubbles in spirit thermometers cannot be removed in this way, but as described on page 8.

Except in the case of the maximum thermometer, swinging will not usually result in joining the mercury thread, but often in breaking the thermometer itself.



Australian pattern whirling psychrometer G 268/5123

The Thermograph (G 268/2157 or G 268/2158)

The thermograph is designed to give a constant record of temperature and works on the principle that metals expand or contract when subjected to temperature changes.

The actual element consists of two strips of metal, welded together and then wound in the form of a spiral. These strips are of metals with a widely different coefficient of expansion, the strip made with the metal of the lesser coefficient forming the outer surface.

Changes in temperature cause a winding or unwinding of this spiral the movement being transmitted to a pen arm which traces a line on the chart attached to the drum.

Calibration and Adjustment of Thermograph

The thermograph gives a constant record of temperatures by means of a trace marked on a chart by a pen, the pen movement being controlled by a bi-metallic coil. The clock may either revolve once daily (using a daily chart) or once weekly (using a weekly chart). The chart covers a range of 75° F.—usually, but not necessarily, reading from 30° F. to 105° F.

Before testing, the instrument must be clean and working quite freely. Light oil should be applied to the bearings.

It is also necessary to have the correct length of pen arm so that by swinging the pen the mark will be parallel to the time lines. The pen should not bear too heavily on the paper, otherwise friction will not permit free movement of the mechanism. The pressure on the paper can be varied by altering the angle of elevation of the gate support for the pen arm. The instrument may be tested either in the screen or in a special chamber.

Testing in the chamber is the more satifactory method but is not possible for field work, the calibration being executed in the screen.

The instrument may have two principal errors:—

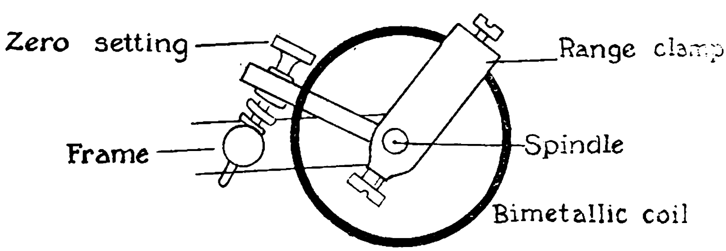
(a) The zero adjustment may not be correct;
(b) The range value may not be correct.

If the zero adjustment is not correct but the range value is correct, the instrument will give a temperature record that differs by a constant amount from the true temperature, that is, the thermograph may show 2° low over the whole scale. This error is rectified by adjustment of the vernier screw until the instrument reads the correct temperature. If (b) is correct the instrument will now read correctly over the whole scale.

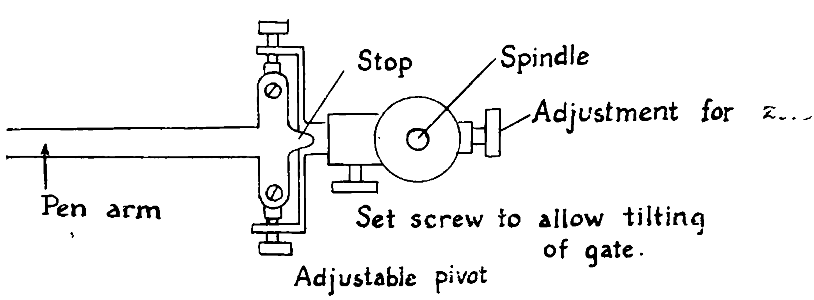
To test for (b) leave the instrument in the screen for 24 hours and compare the temperature range between the maximum and minimum points on the record with the temperature range as indicated by the maximum and minimum thermometers. If the range value is correct these ranges will be the same.

The older model instruments have no adjustment but the modern types are provided with a clamp to bring more or less of the bi-metallic coil into use. If the instrument under test does not cover the full range between the maximum and minimum temperatures a larger amount of the coil has to be brought into use and vice versa.

It should be noted that in cases where the trace shows that the extreme was of very short duration the heat capacity of the thermograph may cause an appreciable difference between the true temperature and the recorded temperature.



Adjustment points on bi-metallic thermograph



Gate on pen arms fitted to thermograph and barograph

SECTION 3

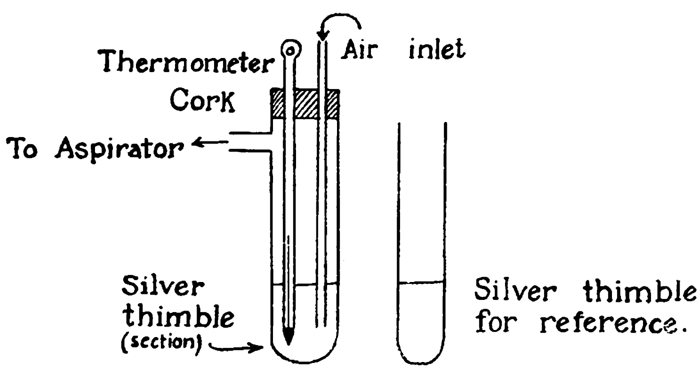
HUMIDITY

At any time a given sample of air contains some water vapour, the amount being generally less than that required for saturation.

The relative humidity is defined as the ratio of the mass of water vapour in a given volume of air to the mass of the water vapour required to saturate the same volume of air at the same temperature. The relative humidity may also be expressed as the ratio of the vapour pressure of the water vapour in the air to the saturation vapour pressure at the same temperature.

The saturation vapour pressure decreases as the temperature decreases and thus the amount of water vapour required for saturation decreases as the temperature is lowered. So if the temperature of the air be lowered the mass of water vapour present in the air will be unaltered and a temperature will be reached where the actual mass of water vapour present in the air is sufficient to saturate the air at this lower temperature. At this temperature moisture is deposited and the temperature is called the **dew point.** It is clear that the actual pressure of the water vapour in the air at the dry-bulb temperature is equal to the saturation vapour pressure at the dew point; hence the relative humidity is given by the ratio of the saturation vapour pressure at the dew point to the saturation vapour pressure at the dry-bulb temperature of the air.

This is the basis of the dew point hygrometer. Once the dew point and dry-bulb temperature of the air are known, the saturation vapour pressures at these temperatures are found from tables, and the ratio of these two pressures, expressed as a percentage, gives us the relative humidity.



The dew point hygrometer consists of a thin and highly polished thimble containing ether, into which dips the bulb of the thermometer. Air is blown or drawn through the ether, which produces a cooling effect proportional to the rate of evaporation

of the ether. When the temperature of the outside surface of the thimble reaches the dew point of the air outside, moisture will be seen to form on the silver thimble. Owing to the high conductivity of silver and the constant stirring caused by the current of air, it is obvious that the thermometer must indicate very nearly the temperature of the external surface of the thimble. In order to recognise the first appearance of dew by comparison a second silver thimble is set near the first. The temperature of the air is given by another thermometer which is placed inside the second thimble which is perforated to allow free circulation of the air. This instrument becomes useless if the dew point is much below freezing point as ice tends to form in the tubes carrying the air. Readings cannot be taken with accuracy for the disappearance of the dew, owing to temperature gradients being set up within the ether, in the absence of the stirring motion of the air.

Wet and Dry Bulb Hygrometer

The principle of the psychrometer or wet and dry bulb hygrometer is the lowering of temperature due to evaporation. The dry bulb is an ordinary sensitive thermometer, and set by its side is a similar thermometer which has its bulb kept constantly moist by a wrapping of muslin to which is attached a wick dipping into a reservoir of pure water.

The drier the state of the atmosphere, the more rapid will be the evaporation of water from the ~~dry~~ bulb, hence the greater will be the cooling effect, hence the greater the difference between the dry and wet bulb temperatures. Conversely, when the humidity is high, evaporation is slow, cooling is slight, and the difference between dry and wet temperature is small.

From the wet and dry bulb temperatures, the relative humidity can be ascertained from appropriate tables.

Various empirical formulæ have been devised to give humidity values from wet and dry temperatures for various wind velocities. Tables are available for the following wind velocities:—

0 - 0·5	metres per sec.	
1 - 1·5	,, ,, ,,	Stevenson Screen.
2·5 - 40	,, ,, ,,	Aspirated Psychrometers.

All humidity tables for use with the Stevenson Screen are calculated for the 1-1·5 m/sec. range. On dry, hot days, when the wind is less than 0·5 m/sec., the use of these tables may give errors up to 20%. For this reason, use either the Whirling Psychrometer or the Assman's Psychrometer, which ensures that the velocity of the wind is greater than 2·5 m/sec., using, of course, tables calculated from the appropriate formula. These instruments are constructed in a similar way to the Whirling and Assman thermometers which have already been described. If the wet bulb is below freezing point, before reading the wet bulb thermometer

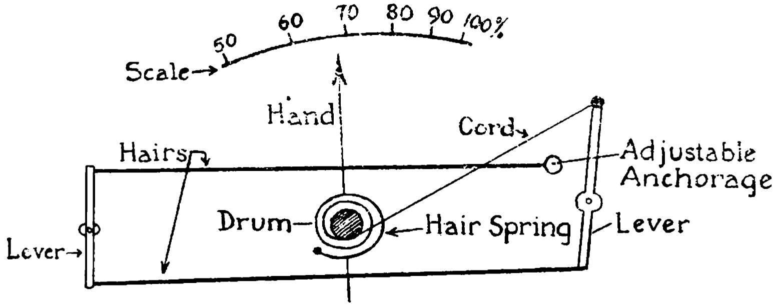
a thin coating of ice must be placed on the muslin and bulb, by painting it with ice water, and then read until the temperature becomes constant.

Full instructions for use of wet and dry bulb hygrometer are given in A.O.H., page 37. These instructions should be carefully studied.

The Hair Hygrometer (G 268/5106)

Many organic substances alter their dimensions when exposed to moisture, for example, cellophane, wood, hair; but do not change appreciably with temperature. The contraction and expansion of such substances, therefore, may be used as a measure of humidity. Human hair is the most generally used, and must be carefully treated to remove all grease, usually by boiling in caustic soda. The length of the hair increases with an increase of relative humidity and vice versa, but the changes are not in proportion, that is to say, a change of 5% in the relative humidity at the top of the scale, say from 90 to 95%, gives a much smaller change in the length of the hair than an equal change lower down in the scale, say from 25 to 30%. Owing to its simplicity of operation, it is perhaps the most widely used form of hygrometer. There are several disadvantages, the chief being the rather large lag which renders the hygrometer insensitive to rapid changes in humidity, that is, if the relative humidity suddenly jumps from 10% to 70%, the hygrometer may indicate 65% immediately and then slowly move to 70% in perhaps a few hours.

The hair hygrometer consists of two bundles of hair arranged as in drawing. Any change in length of the hair is communicated to the drum on the hand spindle. The dial calibrations are crowded at the upper end due to the unequal change in length of the hair for equal humidity changes.



Hygrograph (G 268/5101 or G 268/5102)

As the name suggests, this instrument is used to give a constant record of the relative humidity of the atmosphere.

A small bundle of hair is used for actuating the lever carrying the recording pen. The bundle of hair is held by two jaws, and

caught up at approximately its centre by a hook. The horizontal axis of the lever to which a hook is fixed, is fastened to a cam piece which is kept in contact with a second cam piece by means of a light spring. The second cam piece is clamped to the pen arm axis by a screw. Alterations in the length of the hair with humidity are in this way magnified and communicated to the pen. The greater part of the magnification of the changes in length of the hair is produced by the pen arm and the lever, although some magnification is produced by the angle in the hair and by the cam pieces.

It is mentioned above that the change in hair length, due to a change of 5% in relative humidity, is greater from 25 to 30% than from 90 to 95%. This would result in correspondingly different pen movements at these two places on the chart. The cam link motion between the pen and hair has been designed to eliminate this, so that the pen will have the same movement for, say, 5% change in relative humidity at any point on the range from 0 to 100%.

All parts of the instrument should be kept clean and all moving parts working freely. Sparing quantities of very light oil should be used on the pivots. The hairs should never be handled by the fingers as contamination by grease will ruin their efficiency. They should be occasionally treated with benzol or ether to ensure freedom from grease, and about once per week wetted with clean water, applied with a camel hair brush. The instrument should then show a reading of approximately 95%, the weight of water on the hairs preventing a reading of 100% being recorded.

Calibration

Before calibration or use the hair hygrometer or hygrograph should, if possible, be stored in an atmosphere of high humidity (80% to 90%) for about twelve hours. If they are exposed to low humidities for any considerable period, the hairs appear to acquire a semi-permanent set, which can, however, be removed by again storing at high humidities.

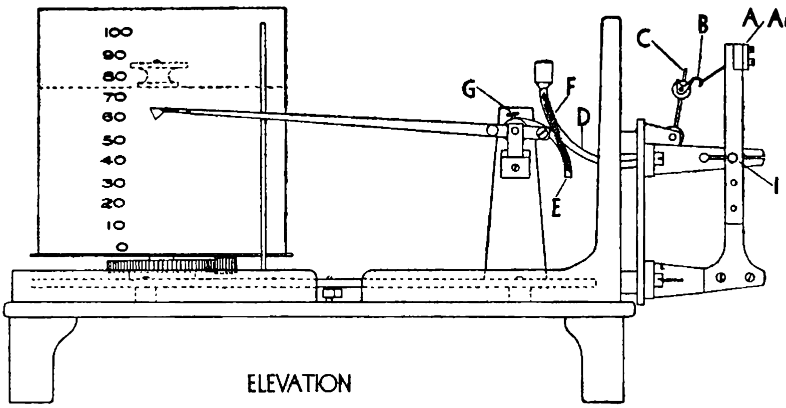
Hair Hygrograph—Tests and Adjustments

The instrument may be tested in a special calibration cabinet or in the temperature screen. The former method is the more satisfactory but is possible only at the Central Office. If using the screen to test the hygrograph, the humidity as given by the dry and wet bulb thermometer is accepted as the calibration standard.

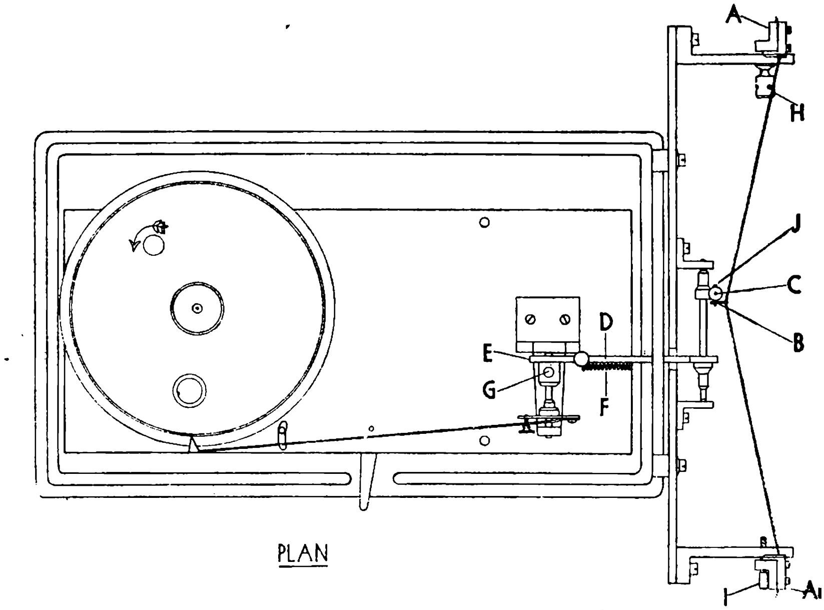
In general, two adjustments are necessary:—

(1) For zero error; (2) for scale value.

HAIR HYGROGRAPH



ELEVATION



PLAN

R.O.W
CENTRAL WEATHER BUREAU
MELBOURNE

(1) For zero error—

(a) Large adjustments for zero error should be performed by moving the jaw between which the hairs are clamped; this can be done by unscrewing the capstan-headed screw of the "back" jaw.

(b) Small adjustments for zero error (within 5% relative humidity) may be made by turning the small screw on the "front" jaw with the small end of the clock key. Large alterations of the angle in the hair affect the magnification and should be avoided.

(2) For scale value—

(a) The magnification may be very nearly proportionately increased or decreased by lowering or raising the hook on the lever.

(b) The magnification may also be varied by rotating the pen arm axis relative to the cam pieces. For this purpose the screw locking the lower cam to the shaft is utilised. Clockwise rotation of the pen arm decreases the magnification over the whole range of the chart, whilst anticlockwise rotation has the contrary effect.

(After either (a) or (b) have been carried out the zero error must be corrected as in (1).)

A small secondary effect of clockwise rotation of the pen is that the magnification is decreased to a slightly greater extent towards the bottom of the chart than the top and vice versa. A little experience with a hygrograph will show that the humidity of the air varies very rapidly, so that small errors in the time scale may become very serious.

For the same reason, the comparison of the values of the humidity obtained from the tables with simultaneous values calculated from dry and wet bulb readings is difficult.

Another cause of difference lies in the fact that the reading of a wet bulb depends to some extent on the rate at which air is flowing past it, but the measurement of R.H. by a hair hygrograph is almost entirely **independent** of wind velocity. A single comparison is thus of little value, but in a long series of observations the mean difference between the readings should be small.

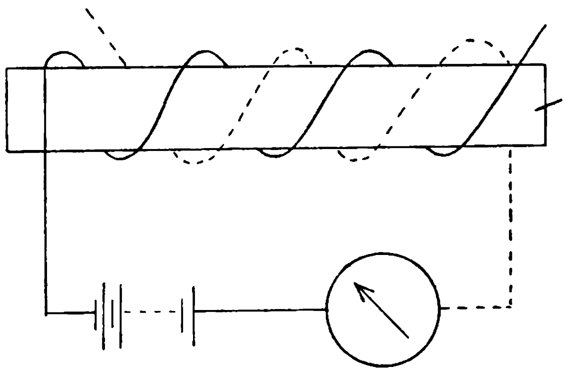
Electric Hygrometers.

This instrument utilises the variation in the conductivity of the air with increase in water vapour content to measure relative humidity. If we arrange two wires adjacent to one another and with a voltage across them, then the current flow will depend on the conductivity of the air between them.

This type of hygrometer is in the experimental stage and is not in general use anywhere, but has been developed for use with radiosondes. The main difficulties yet to be overcome are:—

(i) The resistance depends upon the past history of the instrument and has a definite temperature effect;

(ii) The relation between the relative humidity and resistance is not linear, closing up at each end of the humidity scale.



Using a circuit as in the above diagram, the current ranges for various humidity ranges were found to be somewhat as follows:—

Relative Humidity	**Current**
10%-50%	0-10 microamps
50%-70%	10-90 ,,
70%-100%	90-100 ,,

This depends, however, on the hygroscopic covering on the wires.

Accuracy of the Various Hygrometers

Using a good Screen (W. & D.B.)	Extreme G.P.E.	± 20%
,, a Sling	,,	± 2%
,, an Aspirator (Assman)	,,	± 1%
,, a Hair Hygrometer	,,	± 2%
,, an Electric	,,	± 1%

AN IMPROVED ELECTRICAL HYGROMETER

The psychrometer and hair hygrometer are common means of determining the moisture content of air. There are, however, many circumstances to which these are not well adapted, especially in the measurement of upper-air humidities by means of radiosonde, where marked and sudden changes of humidity are encountered. In fact, when humidity readings are to be made or recorded graphically, remote from the point of measurement, or where humidity must be determined rapidly, or in confined spaces, or at low temperatures, these methods are not practical.

A type of electrical hygrometer better fulfils the requirements. The unit consists of a $\frac{3}{8}$-in. diameter, 0·01-inch thick aluminium tube 1-11/16ths inches long, coated with polystyrene resin, and wound with a bifilar winding comprising 20 turns (of each wire) per inch of No. 38 A.W G. bare palladium wire. The unit is then coated with a thin film of partially hydrolized polyvinyl acetate, with the addition of a small amount of lithium chloride, the amount depending upon the humidity range to be covered by the unit. The electrical resistance of the film between the two coils is a function of humidity.

The thin-walled aluminium tube enables the unit to assume quickly the temperature of the air, as it must if measuring relative humidity. The use of palladium wire eliminated a continuous ageing effect of increase in resistance caused by a film which continued to form on the surface of all other wires previously used. The polystyrene resin forms an excellent water-resistant base, of high electric resistance, for the wire and water-sensitive film. This construction eliminated hysteresis effects previously experienced, caused by the absorption of water by glass and other materials used as bases.

The polyvinyl acetate forms a porous binder for the lithium chloride, which not only gives stability and uniformity to the units, but also greatly reduces polarization effects previously experienced when using the electric hygrometer in the D.C. radiosonde circuit.

A method is provided which makes possible the measurement of relative humidity from 10% to 100%, by using several units of different sensitivities in parallel, with resistors in series with each.

Electric hygrometer units have been made which have not varied more than 2 or 3% over a period of several months.

IMPROVEMENTS OVER EARLIER DEVICE

The improvements incorporated in the new electric hygrometer may be classified under four headings:—

(1) Prevention of long-period ageing.

(2) Prevention of hysteresis effect, or short-period ageing.

(3) Use of partially hydrolized polyvinyl acetate film—
  - (a) as lithium chloride binder
  - (b) gives a homogeneous film
  - (c) results in a reduction of polarization. The actual reason for this is not known.

(4) Special design for covering the full humidity range without switching means.

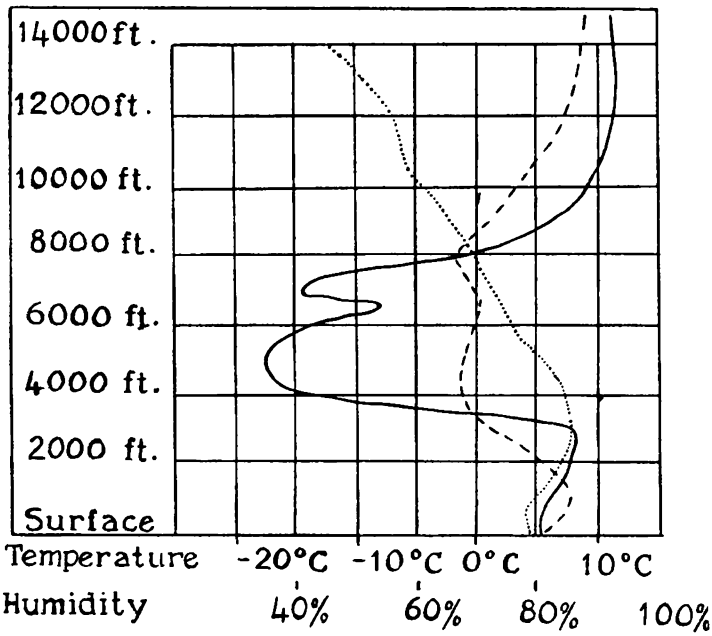
Prevention of Long-Period Ageing

As palladium is cheaper than platinum, the former is now used. Units wound with this wire have been found to hold a calibration to within $\pm$ 3% for six months. Twenty bifilar turns

per inch of No. 38 A.W.G. gave the best results. A reduction in the number of turns per inch decreases the current density at the surface of the wire, which tends to increase the polarization effect in the D.C. circuits, and to decrease the life of the unit in A.C. circuits. Fewer turns, however, make a unit which covers a greater range of humidity for a given resistance change. With amplifying means between the unit and indicating instrument it is possible that fewer turns might be used.

Temperature Correction

The electric hygrometer functions like an electrolyte in that its resistance increases with a decrease in temperature. In radiosonde use, where temperature variations of 100° C. are encountered, it is, of course, necessary to apply a correction to obtain the true humidity. It has not been found possible with a single-element unit to cover the full 10-100% humidity scale over this extreme temperature range; but it has been possible with a composite unit.



This shows the comparison between a hair hygrometer and electric hygrometer for simultaneous ascents.

Note the rapid response of the electric type and the lag of the hair type at low temperatures.

The rate of ascent was 800 feet per minute.

Continuous line is electric hygrometer.

Broken line is hair hygrometer.

Dotted line is temperature.

SECTION 4

MEASUREMENT OF ATMOSPHERIC PRESSURE

Pressure is defined as force per unit area and is generally measured in terms of weight.

Atmospheric pressure measurement (Barometry) is usually accomplished by one of two general methods:—

(a) Balance the pressure against a column of liquid whose weight is known.

(b) Utilize the elastic properties of a thin metal membrane exposed to the pressure.

Liquid Barometers

Choice of Liquid

Mercury is usually adopted as a liquid for the following reasons:—

(i) It has a high density which reduces the length of the column to a minimum.

(ii) Its vapour pressure is very small at ordinary temperatures.

(iii) It is opaque and therefore its height can easily be ascertained.

(iv) It does not wet glass.

Measurement of Height of Column—Two Main Methods

(i) Using a cathetometer which gives a high accuracy but is too cumbersome for ordinary work.

(ii) Using a scale set up near the mercury column on the barometer with a suitable vernier.

Units of Measurement of Pressure

(1) **The Mercury Unit:** Since the principal item in the determination of pressure by the mercury barometer is the measurement of the height of the mercury column, it is natural that the scale of this instrument should be graduated in pure length units, i.e., in inches or millimetres, the English standard of length being defined at a temperature of 62° F., this being the mean temperature of the British Isles. The inch barometer is designed so that when its temperature is 62° F., the scale measures the correct height of the column. Similarly the scale of a metric barometer measures the height of the mercury column correctly when the temperature of the instrument is 0° C.

The measurement of barometric height is only part of the complete determination of pressure, since the condition of the mercury has not yet been defined. This is done by specifying the mercury to be under standard conditions of temperature and gravity. Standard gravity is defined as a value of gravity at sea

level in latitude 45°. Standard temperature has always been taken as 0° C. for mercury. It is customary to regard the expressions mm. of mercury as implying that the mercury is under standard conditions, and thus these expressions can be used to represent the actual pressure. It is advisable, however, to specify the conditions when referring to pressure in these terms.

There is a third unit, an absolute unit of pressure frequently employed nowadays in the graduation of scales of both mercury and aneroid barometers, particularly meteorological barometers. This unit is the "bar"; it belongs to the c.g.s. system of units, and is defined as a pressure of one million dynes per square centimetre.

The millibar unit was adopted by the London Meteorological Office and the United States Weather Bureau in January, 1914. The millibar being a derivative of a dyne is dependent on the value of "g," but any change of the value of "g" due to height is usually neglected.

2. **The Standard Atmosphere:** Whilst the millibar is established among meteorologists generally, the point of view of the pure physicists still favours the retention of the "m.m." together with the "standard atmosphere."

The standard or normal atmospheric pressure is defined as the pressure due to the weight of 760 mm. of mercury at 0° C. and at sea level in latitude 45°. This is equivalent to 1013·23 millibars.

The meteorologist is inclined to regard his standard atmospheric pressure as 1000 millibars (i.e., one megadyne Cm^{-2}) which is equivalent to 750·076 mm. of mercury.

PARTS OF MERCURY BAROMETER

(a) The Glass Barometer Tube

The barometer tube, necessarily closed at the upper end, which is usually about 33" above the fiducial point, is usually made of lead glass. The fiducial point is taken to be the surface of the mercury in the cistern. The bore of the tube is fairly uniform and varies from ¼" to ¾", depending upon the accuracy required, larger bores giving more accurate results because there is less capillary depression. The most suitable size is between 0·4" and 0·5"

(b) The Barometer Scale

It is a convenience to engrave the barometric scale on the metal sheath of the tube. This is usually done, and incidentally brings the scale as near as practicable to the mercury column. The scale is silvered and the graduation lines blackened for clearness.

Barometers usually have two scales, one on either side of the mercury column in different pressure units. The length of the

graduated scale depends upon the station at which the barometer is to be used. At sea level the maximum range of variation in atmospheric pressure is 31·1" to 27·3" of mercury. If the barometer is to be used below sea level (e.g., in a mine) the upper limit of the scale must be increased; and similarly for readings at high altitudes the lower limit must be increased. Generally for high altitude use specially designed barometers, known as Mountain barometers, are used.

(c) **The Vernier Scale**

In order to read accurately to a fraction of a division on any scale it is necessary to use an attached sliding scale called a vernier.

Take nine equal divisions on a fixed scale "A" and on an adjacent sliding scale "B," mark off a length equivalent to these nine divisions. Divide this length "B" into ten equal parts, then one part on the vernier scale "B" will be equal to 9/10ths of a division on the fixed scale "A" or there is a difference of 1/10th of a **fixed scale division** between each division on the two scales. If, therefore, the divisions on the fixed scale were 1/10th of an inch apart then the vernier scale would read to $1/10 \times 1/10'' = 1/100''$.

In considering the barometric scale we find that the 25 divisions on the vernier scale correspond to 24 divisions on the fixed scale, so that there is a difference of 1/25th of a **fixed scale division** between each division on the two scales. As each small division on the fixed scale is 1/20th of an inch the vernier will read to $1/25 \times 1/20''$ or ·002" and by interpolation it can be made to read to 1/1000" or ·001". For accurate readings the bottom of the vernier slide must be perfectly horizontal with a good background illumination. This is necessary to ensure that the zero of the vernier scale and the top of the mercury meniscus are in the same horizontal plane.

(d) **The Attached Thermometer** (G 268/5080)

A mercury-in-glass thermometer is a necessary adjunct to a mercurial barometer because of the high thermal expansion of mercury.

The position of the attached thermometer is very important as it is required to register—

(1) The mean temperature of the brass scale.

(2) The mean temperature of the mercury column.

Yet it is not certain that the barometer will be used in surroundings free from considerable vertical and horizontal temperature gradients. Accordingly the best plan in general is to mount the thermometer with its bulb as near to the centre of the barometric column as practicable. The attached thermometer should be read first so as to avoid the effects of radiation from the body.

The Kew Type Barometer

The old type Fortin barometers required two settings to give a reading of the atmospheric pressure. The Kew barometer was designed to eliminate one of these settings.

If the cistern and the glass tube of the barometer are cylindrical, the change in the level of the mercury in the cistern corresponding to a given pressure change is a definite fraction of the change of level of the summit of the mercury column, and the value of this fraction depends only upon the dimensions of the instrument, assuming at this stage that the temperature is constant. It will be readily seen that the movement in the tube is always smaller than that which would be obtained if the mercury in the cistern were brought to a fiducial point. Accordingly the scale is contracted to allow for this smaller movement. This contraction obviously is dependent upon the cistern diameter and the tube diameter. By agreement only two contraction values are allowed, namely those in which the nominal inch of the scale measures 0·96" and 0·98". The former is the more normal contraction used, the latter, however, giving higher accuracy.

A diagrammatical sketch of the barometer is given in Fig. 1.

Suppose when atmospheric pressure rises by one inch, the mercury rises in the tube "x" inches and falls in the cistern "y" inches.

$$\text{Then } x + y = 1 \quad \ldots\ldots\ldots\ldots \quad (1)$$

but the volume change in the cistern and the tube must be equal,

$$\text{thus } \pi\, d^2x = \pi\,(D^2 - t^2)\, y \quad \ldots\ldots\ldots\ldots \quad (2)$$

Substitute for y in (2) and divide by π

$$d^2x = (D^2 - t^2)\,(1 - x)$$

$$xd^2 = D^2 - t^2 - x(D^2 - t^2)$$

$$x = \frac{D^2 - t^2}{D^2 + d^2 - t^2} \text{ of an inch.}$$

This must be less than a true inch since $D^2 + d^2$ is greater than D^2; i.e., numerator is smaller than denominator.

Several points are worthy of special notice. To minimise the chance of air bubbles finding their way into the space at the top of the tube, the tail-piece T of the tube (i.e., the bottom) is drawn to a fine point. In addition an air trap is provided a short distance up from the bottom of the tube. To do this, portion of the tube is drawn out into a capillary and at the bottom, A, of this capillary is attached a short tube tapering to a fine point at B, projecting into the main body of the barometer tube. Any air bubbles which might find their way through the fine point at T are generally trapped in the space between the outer tube and the small inner tube AB. The chance of a bubble getting through B is very rare.

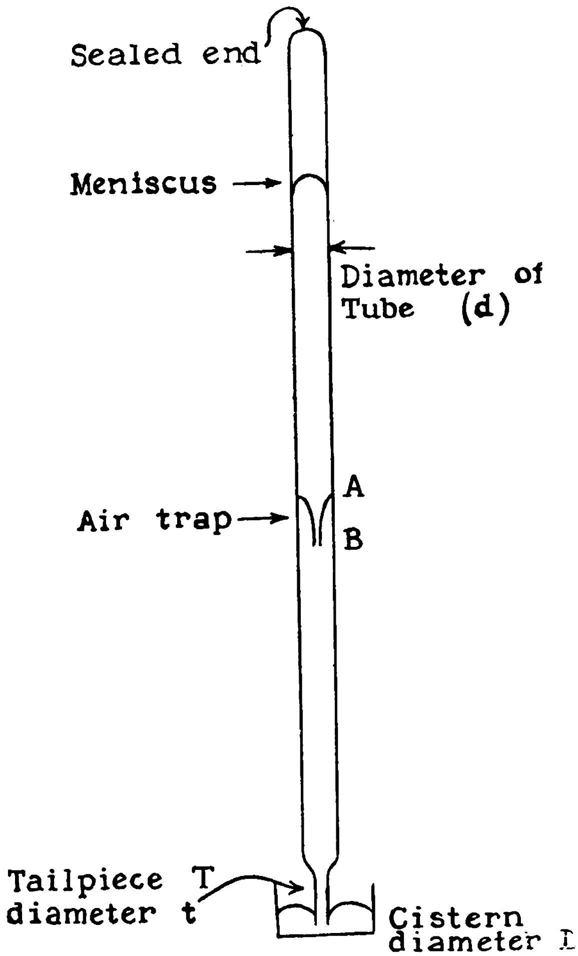


Figure 1

The Kew Pattern Marine Barometer (G 268/5055)

As the oscillation of the mercury was a serious obstacle to the taking of readings aboard ship, the capillary in the barometer tube is made extremely fine in the marine type of barometer, so as to oppose the flow of mercury through it. This tends to damp out any oscillation or "pumping" as it is technically called. In other respects it is essentially the same as the ordinary type.

Transport of Barometers

The barometer is gently tilted until the tube becomes full and then it may be carried in an inverted or horizontal position.

Though every care must be taken to prevent the entry of any air into the tube, the constriction and air traps render this barometer less dangerous than the Fortin in this respect.

Reduction of the Readings of a Mercury Barometer to Station Level

There are four types of corrections necessary to reduce barometer readings to station level.

(1) Index error.

(2) Temperature correction which involves corrections for the expansion of the brass scale, the mercury column, the cast iron cistern and the glass barometer tube, also vapour pressure of mercury.

(3) Gravity or latitude correction, due to variation of gravity with latitude.

(4) Capillary depression in the tube and the cistern. This depression is appreciable up to ½" bore tubing and its value depends upon the angle of contact. In most barometers approximate values of this depression are obtained and are corrected for in calibration.

Accuracies of different Barometers

(i) Standard Fuess ± ·001" (type used as standard at C.M.B.)

(ii) Station Barometer ± ·006".

(iii) Travelling Standards and Aneroids ± ·006". These must be tested before and after inspection tour.

Reduction of Barometer Readings to M.S.L.

Barometer readings taken at places at different levels cannot be directly compared until they have been reduced to the same level. Synoptic charts are based on simultaneous readings taken at a large number of stations and the readings have to be reduced to common level before they are entered on the charts. M.S.L. is almost universally adopted as the common level. (In South Africa, however, they take 5000' as their datum level and make seasonal corrections.) To make the reduction the observed reading (duly corrected for index error, temperature and latitude) has to be increased by an amount equal to the pressure exerted by a column of air equal in height to the height of the station, under corresponding conditions of pressure and temperature. As the column of air is a fictitious one, certain assumptions have to be made. To obtain the mean temperature of this fictitious column of air, the temperature at the station is taken and a lapse rate of 1·98° C. per 1000 feet allowed. Generally, also the humidity is taken as being 50%, though if necessary corrections can be made for this. These standards are only used if the station is over

1000 feet high; if it is below 1000 feet humidity is neglected and the temperature at the top of the column is taken to be the mean temperature of the column. The average correction amounts to about 1 inch increase in pressure per 1000-foot decrease in height. This method, obviously, is subject to many errors, due mainly to the fact that local heating gives readings not representative of the air temperature and observed lapse rates are quite often very different from the accepted value, varying from a negative value to a maximum positive value of about 3° C. per 1000 feet. Errors introduced in this way may amount to $\pm$ 0·1 inch.

The Gold Slide (G 268/5071)

In the reduction of a barometer to standard conditions we have to apply the following corrections:—

(i) The index correction.

(ii) Temperature correction to the barometer (attached thermometer).

(iii) The latitude correction (gravity).

(iv) The height correction (involving air temperature).

Gold devised an attachment which enables these corrections to be obtained as one correction by the mere setting of a scale. It is used chiefly on ships and low level stations. The Gold slide, as it is called, is illustrated diagramatically in Fig. 2.

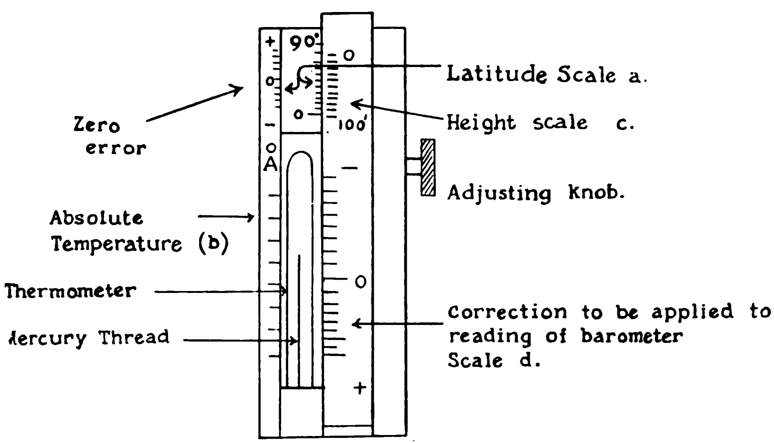


Fig. 2.

It will be seen that there are four scales involved:—

(a) The Latitude scale (fixed).

(b) The Attached Thermometer (fixed).

(c) The Height scale.

(d) The scale giving the correction.

(c) and (d) are fixed relative to each other, but can be moved up and down by a thumbscrew. It is assumed that the tempera-

ture of the air is the same as that of the attached thermometer. To obtain the correction the height above M.S.L. is set against the latitude of the barometer—this moves the correction scale up or down. The correction is read on the correction scale against the top of the mercury thread of the attached thermometer. The index error is eliminated by setting the latitude scale initially against an index correction scale and then locking the small slide in this position.

DISMANTLING OF A KEW PATTERN MERCURIAL BAROMETER

First, incline the instrument very gently, so as to allow the mercury to flow very slowly to the top of the tube. With the tube thus filled the barometer may be transported with safety in a horizontal or inverted position.

The attached thermometer mounting is to be removed, and before withdrawing the tube and cistern it is necessary to remove the small grub locking screw in the barrel adjacent to the cistern, Withdraw the tube and cistern with the tube in the inverted position. Carefully bring the tube and cistern to the upright position and stand it on the bench or table. The mercury column may then be examined for air bubbles.

If it becomes necessary to withdraw the mercury from the tube and cistern, remove the screw in the base of the cistern with the instrument inverted and then slowly pour the mercury from the barometer.

The cistern itself may then be dismantled by unscrewing from the collar supporting the barometer tube.

Caution

Mercury should never come in contact with the brass surface of the instrument as corrosion of brass will occur almost immediately. The cover glass protecting the scale is clamped between two brass collars on the barrel of the instrument. After slackening the lower collar remove the top cap. The cover glass can then be taken from the barrel. Small leather washers are placed in the recess of these collars to cushion the ends of this cover glass. The scale may be cleaned with petrol only.

In the reassembly of the barometer care is necessary when replacing the tube and cistern as the cork or rubber buffers protecting the tube when in position in the barrel may not be in place.

SECTION 5

MEASUREMENT OF RAINFALL

Rain Gauges

The standard rain gauge used in Australia is described in B.O.H., page 88. In Australia, however, the flat-bottomed measuring glass is used instead of the tapered bottom described in the handbook. This type renders the measurement of small amounts of rain rather difficult and inaccurate.

Pluviographs

The pluviograph is a rain gauge which records automatically and which is designed to give a record of the time and intensity of precipitation. Several types of pluviographs or self-recording rain gauges are in use and are described in B.O.H., page 125, and A.O.H., page 76. Of these types only the Hellman-Fuess type (G 268/5096) and the natural siphon rain gauge (G 268/5095) are used in Australia. The latter type is now a standard form of pluviograph issued. The instrument consists of three main parts—

(1) The tank;

(2) The float chamber assembly; and

(3) The clock drum.

The tank is a cylinder 8" in diameter, which is the standard size for all gauges used in Australia. The top inside portion is in the form of a funnel with the stem projecting into a brass pipe which contains a fine strainer to guard against clogging of the mechanism by pieces of grass, etc.

A cross section of the float and siphon chambers is shown in the diagram. To prevent dribbling of the water in the position when siphoning is about to commence, the two sections of the siphon chamber are made coaxial and a small glass cap is fitted over the upper end of two tubes. It is essential that this fitting be made airtight. Only a small gap is provided for the water to flow from the outer to the inner tube so that sudden commencement and ending of flow is facilitated and little or no dribbling occurs. The clearance is usually about 1/32nd of an inch.

Attached to the base of the float is a flat rod which slides in a groove to prevent the float from rotating. A light rod which is attached to the top of the float carries the recorder pen. The only adjustment on the instrument is the positon of the pen block on the float rod; this is done by filling the float chamber carefully till it siphons out, then the pen should show zero; if it does not, the block is moved until the pen does indicate zero.

It will be noted from the diagram that a certain amount of water in the float chamber is necessary at all times, otherwise

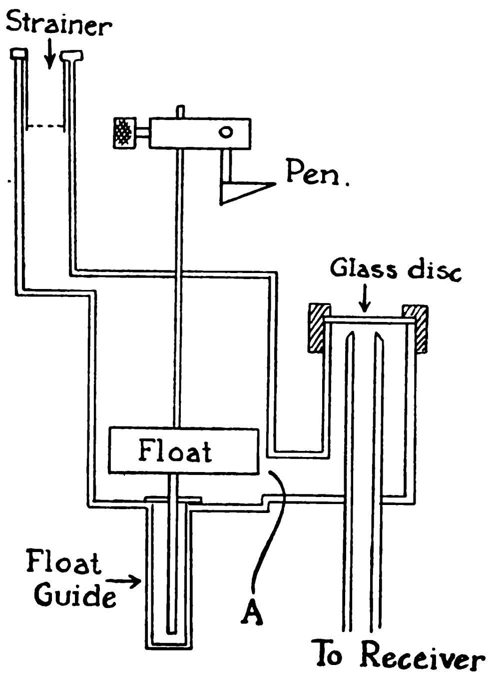
several points of rain may fall before the float begins to rise. The opening from the float chamber to the siphon chamber is in the form of a triangle with the apex upwards. It was found that this particular shape also tended to prevent dribbling by letting the supply of air rise sharply in the outer tube. The siphoning should be completed in about 20 seconds and very little record is lost during the process even at times when heavy rain is falling.

Faults and Remedies of Pluviograph

1. Pluviograph records less than actual rainfall measured in ordinary rain gauge—due to blockage of gauge strainer in entrance to float chamber, causing overflowing and bypassing of float chamber. (Clean strainer.)

2. Siphoning does not completely empty float chamber — usually due to air leak around glass disc, or due to gauze strainer being missing or damaged, letting debris into the float chamber. (Tighten **cap,** replace strainer.)

The clock and drum are the same as used in other self - recording meteorological instruments and the chart is graduated to read up to 40 points or 0·4 inch before siphoning commences. The intensity of the precipitation can be determined by noting the time taken for a certain amount of rain to fall. This information is particularly valuable to engineers in estimating the necessary strength of bridges and the size of drainage systems.



Shape of orifice at A

Casella Instrument

SECTION 6

PILOT BALLOON THEODOLITE

General Description

The Theodolite is an instrument designed to enable both the angle of elevation and the line of bearing (azimuth angle) of any object to be determined. Essentially, the instrument consists of a telescope mounted so that it can rotate in two planes, vertical and horizontal.

For pilot balloon work, various fine adjustments have been introduced. Slow movement of the telescope is obtained by tangent screws, micrometer drums on these tangent screws enabling reading to one-tenth of a degree on continuous run verniers. The tangent screws can be disengaged by throwing out the respective tangent release, thus allowing free movement of the telescope for control by hand. A graticule or scale replaces the usual cross wires.

THEODOLITE PILOT BALLOON

Single Telescope Type (G268/5150). (E. R. Watts and Son.) (See Plate I.)

The following comprises the equipment of this Pilot Balloon Theodolite:—

1 Wooden Case (G 268/5154).
1 Leather Shoulder Sling.
1 Mounting (Field) (G 268/5118).
1 Metal Cover and Plate (G 268/5091).
1 Telescope Extension Tube.
3 Optical Shades.
1 Capstan Bar.
1 Plumb Line.
1 Battery Box containing two $1\frac{1}{2}$-volt dry cells (G 268/5156).

At fixed observation posts, the tripod has been replaced by an adjustable wall head (G 268/5120), i.e., a fixed post, adjustable for height of observer.

At stations provided with a post for the theodolite, on the roof or in some protected site, the metal cover is now being provided which allows the theodolite to be left in position and protected against rain, dust and the sun.

If this is not the case, the theodolite **must** be replaced in the wooden case.

To replace the theodolite, grasp the instrument by the tribrach (T, Plate I). With the tangent screws released, place it in the box with the clamp screw F.3 vertically downwards, the tribrach resting on the rack provided, the eye-piece uppermost, and the

WATTS PILOT BALLOON THEODOLITE

SINGLE TELESCOPE TYPE

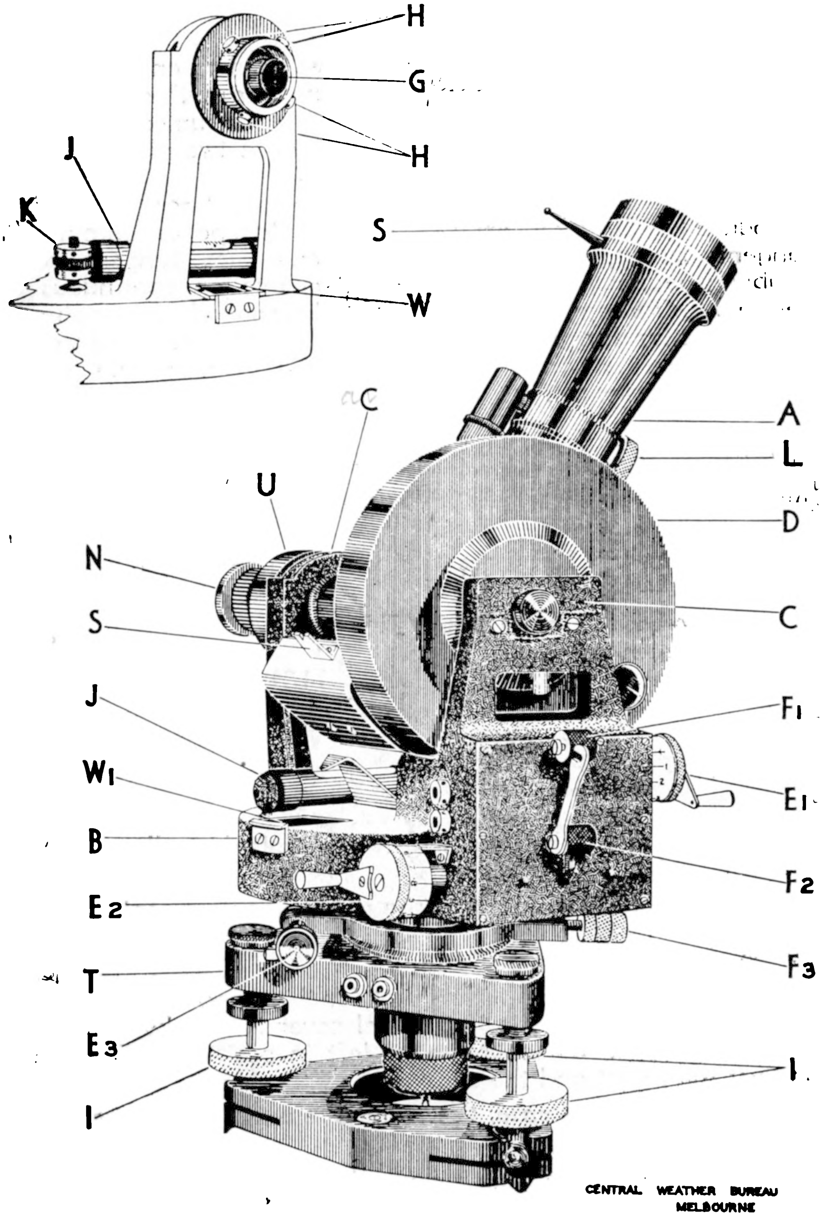


PLATE I.

object glass resting in the rack provided. **Under no circumstances must the theodolite be grasped or held by the telescope**

The instrument consists of a right-angled telescope A carried in bearings CC on standards rising from the plate B. The vertical graduated circle D is rigidly attached to the telescope with its centre on the axis of the eye-piece tube N, and the telescope rotates in a vertical plane with the circle about this axis.

The plate B is supported by a solid cone (termed the inner cone, centre or axis) which revolves inside a hollow cone (the outer cone, centre or axis) carrying the horizontal graduated circle H. The outer cone is seated in the socket of the tribrach T (a triangular plate having three holes for the reception of the levelling screws), and its orientation can be adjusted by means of the clamp F.3 and the adjusting screw E.3. The tribrach is supported on three levelling screws I. which are provided with milled head caps protecting the threads, and acting as adjusting screws, by means of which any wear in the levelling screws may be taken up. The plate B carries a bubble level J. which may be adjusted by means of the capstan screw K. Vertical and horizontal circles are enclosed, the latter by the plate B, to afford protection from dust, windows being provided for reading the scales.

W is the window for reading the scale on the horizontal surface. Fine adjustment of the telescope is performed by means of vernier screws E.1 and E.2, the drums of which are graduated to read to tenths of a degree. In any observation the whole degrees are read on the vertical or horizontal circle and the tenths on the appropriate vernier screw. Each screw is thrown in or out of engagement by an independent lever F.1, F.2, but these levers can be linked so that one movement engages or releases both screws.

TELESCOPE

The optical system consists of an object glass (compound lens), a prism to reflect the line of sight through a right angle, the graticule and the eye-piece (double lens system). The telescope is of a fixed focus type and the position of the graticule in the focal plane may be adjusted by means of the four diaphragm screws under the cover U. The eye-piece is focussed on the graticule by screwing the eye lens in or out. The open sights are indicated by the two letters S.

Plate 11 shows the optical components and the path of rays of light entering the system.

ILLUMINATION

The theodolite is fitted with a 3-volt lighting system for night work. Two small pilot lamps are provided, one situated above the scale window to illuminate the scales, verniers and bubble, and one mounted in a shield on the telescope barrel to illuminate the

graticule. Light from this source is thrown on to a small inclined reflecting surface which is carried on a thin stalk projecting into the telescope behind the object glass. Rotating the stalk by means of the milled head L reflects the rays from the inclined surface down the tube or across it, or any desired intermediate position. The illumination of the field can then be varied continuously from zero. The battery is kept in a small wooden box. A flexible lead from the battery is supplied with a plug fitting into an adapter on the tribrach. A single wire circuit is used, the frame of the theodolite providing the return.

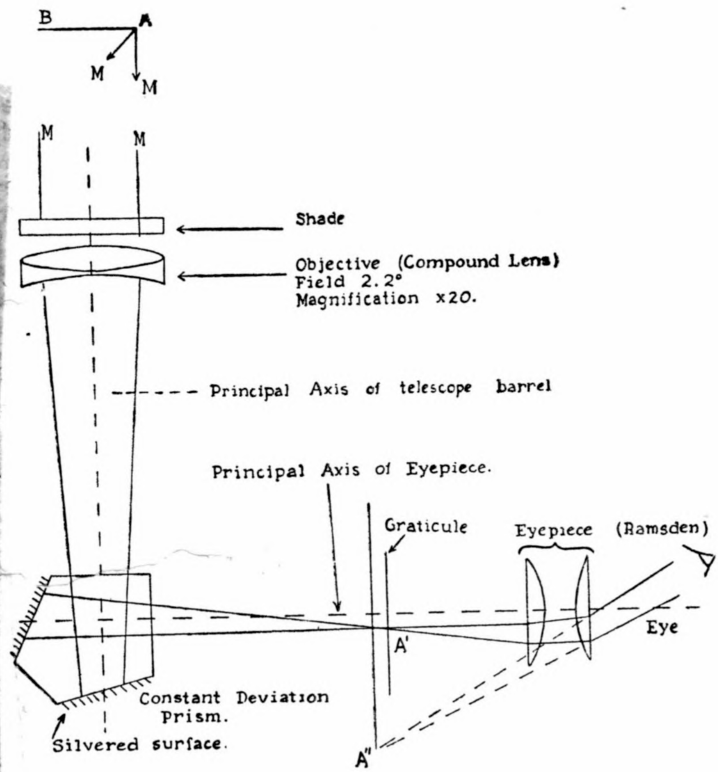


PLATE II

Optical system of Watts Single Telescope Theodolite.

MM are rays from point A of AB, and as AB is at infinity rays are sensibly parallel when entering objective.

A real image A′ of point A is produced on the graticule by objective and a virtual image A″ of A′ and of the graticule is produced by the eye-piece. By suitable focussing of the eye-piece a real image may be projected on a screen held a short distance (6 inches to 12 inches) away from the eyepiece.

TRIPOD

The tripod is provided with a threaded head on to which the sub-base of the theodolite screws. When the tripod is not in use the threads are covered by a protecting cap which screws over the threaded part of the head. The legs can be simultaneously tightened in any desired position by means of a single hexagonal nut located on the side of the head. This nut can be adjusted by means of a key which forms an integral part of the protection cap. A fitting for the protection cap is provided on one of the legs to prevent loss while the tripod is in use.

THEODOLITE PILOT BALLOON, MARK I (G 268/5148)

The following comprise equipment of the Mark I Pilot Balloon Theodolite:—

- 1 Wooden Case (G 268/5153).
- 1 Leather Shoulder Sling.
- 1 Mounting (Field) (G 268/5117).
- 1 Metal Cover complete (G 268/5091).
- 1 Telescope Extension Tube.
- 3 Optical Shades.
- 1 Capstan Bar.
- 1 Plumb Line.

The Mark II theodolite is similar to the Mark I, but has improved gearing and a magnifying glass to facilitate reading the scale, which is divided into half degrees.

Any reference to the Mark I will apply to the Mark II.

No separate batteries are supplied as the lighting system is incorporated in the instrument. If a fixed observation post and metal cover are not provided, the theodolite when not in use must be replaced in the case. To replace the theodolite, grasp the instrument by the tribrach. With the tangent screws released, place it on the box with the clamp screw F.3 vertically downwards, the tribrach on the rack provided, the bubble level horizontal and uppermost, and the objective in the rack provided. **Under no circumstances must the theodolite be grasped or held by the telescope.**

GENERAL DESCRIPTION (See Plate III)

In this new pattern instrument, the optical system and mechanical construction have been altered with a view to more efficient usage.

MECHANICAL CONSTRUCTION AND READING OF CIRCLES

To facilitate reading and to simplify the night illuminating gear, a greater concentration of scales and hand wheels is accomplished by making the elevation circle E run parallel to and immediately above the azimuth circle F, operating it by means of right

PILOT BALLOON THEODOLITE MARK I.

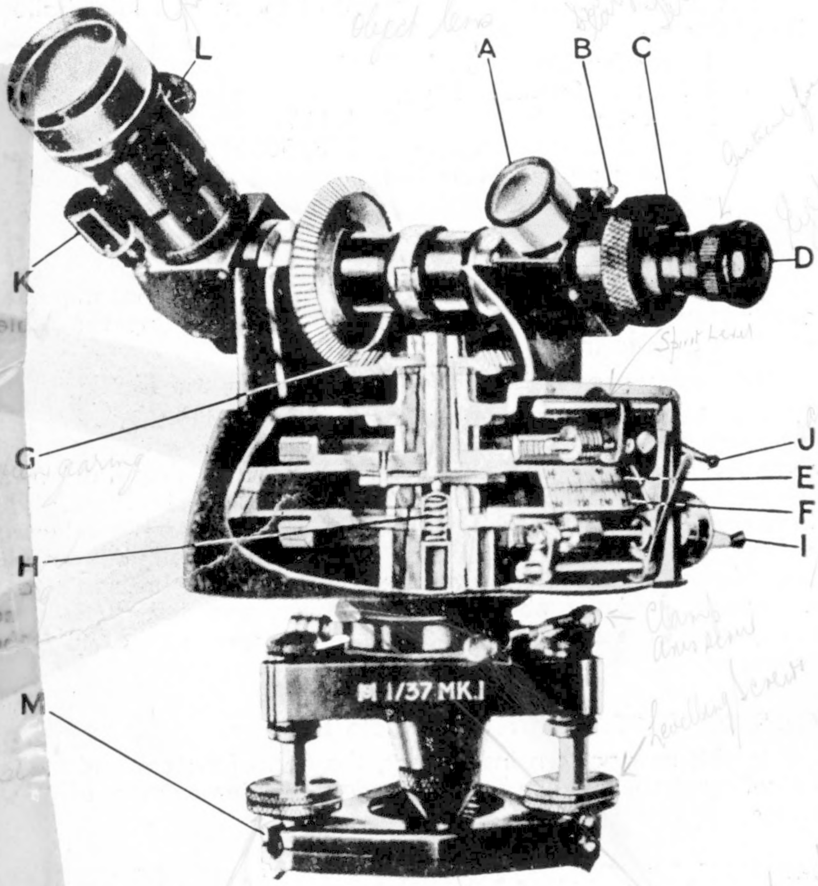


PLATE III.

angle bevel gearing G from the horizontal telescope barrel. As a result of this arrangement, both circles are visible at one window, directly under the eye-piece, and are read against a common fiducial mark (see Plate III).

The spring H which pushes the lower bevel wheel upwards, so that the teeth of the two wheels are kept in close engagement, provides the mean of avoiding backlash and taking up wear in the gear wheels, between the telescope and the elevation circle. The tangent screw control is similar to single telescope theodolite, but the drums have been brought to the front of the instrument to make them more readily visible. The clamps J which disengage the azimuth and elevation tangent screws operate independently so that either circle can be quickly disengaged. The re-arrangement of the scales and vernier drums represent the main departure from the single telescope theodolite, but detailed improvements have been effected—surfaces of the circles lie at a more convenient angle for reading, the fiducial pointers have been replaced by a line engraved on the glass, the vernier drums are slightly coned and provided with double scales and scale marks so that they can be read conveniently from either side of the instrument, and wider window embracing over 20° of arc have been provided.

OPTICAL SYSTEM

The telescope has a magnification of 24 diameters and a field of 2°. The secondary wide-angle telescope of smaller magnification has been incorporated in the design; this consists of a second short focus objective A (Plate III) which can be brought into operation by means of a swinging mirror. The focal planes of the two objectives coincide so that the eyepiece is used for both objectives, and no refocusing or head movement is required. The change over from one field of view to the other is performed by means of the lever B above the wide angle objective. It is to be noted that on changing from one objective to the other the apparent motion of any object in the field of view is reversed. Graticule divisions are correct on the main telescope only. The field of the secondary telescope is 8° and the magnification 6 diameters. This wide-angle telescope is of great assistance for sighting balloons at first release, for night work and for overhead observations.

The theodolite has independent focussing of the eye-piece on the graticule, and of the eye-piece and graticule, **together as one unit,** on the image of an object. The focussing of the telescope is done by a knurled adjusting ring C which moves the eye-piece

and graticule unit to and fro on a helical thread. A thread adjustment for the eye-piece D has also been provided, as an eye-piece which is only a sliding fit in its mount is liable to movement. The rest of the optical system is in accordance with that of the Single Telescope Theodolite.

Plate IV shows the optical components and the path of the rays of light entering the system.

ILLUMINATION

The remodelling of the mechanical system has greatly simplified the illumination of the theodolite, one bulb situated above the scale window being sufficient to illuminate both scales and hand wheels efficiently. This bulb also serves to illuminate a stop watch which may be suspended from the hook provided. To illuminate the field of view a second bulb is carried in a shield K on the side of the telescope barrel. Light from this source is thrown on to a small inclined reflecting surface which is carried on a thin stalk projecting into the telescope behind the object glass. Rotating the stalk by means of the milled head L reflects the rays from the inclined surface down the tube or across it, or in any intermediate direction desired. The illumination of the field can thus be varied continuously from zero. No illumination is provided for the graticule when the low power telescope is in use. The bubble level is not illuminated by the lighting equipment and a torch is necessary for this operation. The two small batteries which provide the current for the night illuminating gear are easily accessible and are housed above the horizontal telescope barrel, so that the whole instrument is self-contained. Switches, one for each bulb, are situated in a convenient position on the right-hand side of the horizontal barrel support.

MOUNTING (FIELD)

This theodolite will fit the solid leg tripod (G 268/5118), but is provided with a new type (G 268/5117), with built-up legs, which is more stable in strong winds.

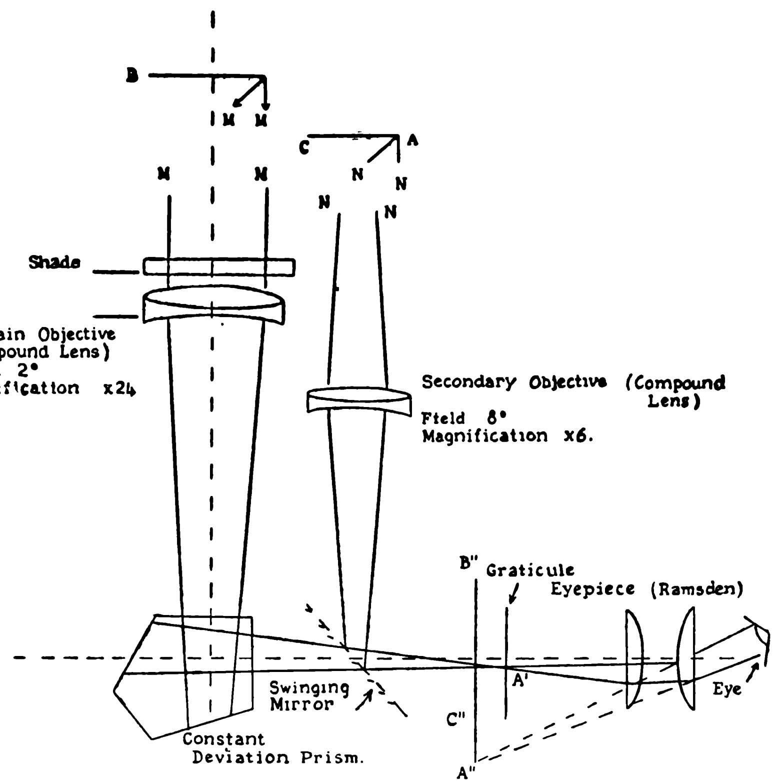


PLATE IV

Optical system of Watts Theodolite Mark I

MM are rays from the point A of AB, and as AB is at infinity these are parallel when entering the main objective.

NN are rays from the point A of AC; AC is at a finite distance and rays are diverging when entering the secondary objective.

C'' Position of C. A''C'' is one-quarter the length of A''B'' when AC and AB are equal distance from theodolite.

A real image of the object is produced on the graticule, and a virtual image of this real image and of the graticule is produced by the eyepiece.

The eye-piece is focussed on to the graticule, and then the graticule and eyepiece together as one unit are focussed so that a clear virtual image is produced.

SECTION 7

THEODOLITE ADJUSTMENTS

Care of Theodolite

The theodolite is a delicate optical instrument and as such should be treated with the greatest of care. **Under no circumstances must the theodolite be grasped or held by the telescope.** Care should be taken not to strain the parts of the theodolite by use of excessive force; parts such a locking nuts, screws, etc., should be screwed home firmly but gently by hand or a capstan pin, but they must not be forced in any way or the threads may be stripped. Diaphragm screws, when finally adjusted, should all have the same tension. If the instrument is being transported to its tripod or from one place to another, care should be taken to avoid jarring it and to prevent any strain being thrown on the axes. All clamps should be loosened ~~tightened~~ before transporting the instrument. Attention should also be given to the condition of the tripod, all nuts and bolts should be tightened up against the woodwork and when shoes are fitted to the tripod they should be kept sharp. When the instrument is in use and it is required to transit the theodolite or to rotate it in azimuth, it is important that the tangent screw slow motions should be completely disengaged from their respective circles, otherwise the teeth will become worn and useless in a short time.

Cleanliness of the instrument is as important as careful handling. Dust in the bearings increases the wear and tends to clog the parts, while dust on the lenses results in an unsatisfactory condition of the field of view. When cleaning an instrument no abrasive such as emery should ever be used. Dust should be removed by means of a camel-hair brush. If necessary, mechanical parts may be cleaned with a little watch oil, the oil being finally removed with a dry piece of cloth. If the motion of the levelling screws is stiff or gritty, loosen their adjusting screws, clean the threads of the levelling screws, vaseline them, wipe clean, and then re-adjust. The surface of lenses should be dusted with a camel-hair brush and smears should be removed by cleaning the surface with petrol and a piece of clean tissue paper. Before replacing the lenses any particles of fluff left on the surface should be removed with a brush. Tubes, sockets and cells must be clean and dry before the lenses are replaced. Compound lens systems should never be dismantled. The graticule may be kept clean in the same way. If the scale markings on the graticule are not clear, the graticule may be rubbed with tissue paper smoothly marked with a soft pencil.

Details of Tests and adjustments (applicable to both types except where specially stated)

1. **Focus**

(a) Theodolite, Single Telescope Type.—Sight the telescope towards the sky and adjust eye-piece. Focus until a clear image of the graticule is visible; next sight the instrument on to a distant object and if this distant object is not in focus, the graticule is out of position and the instrument is to be reported as unserviceable. No adjustment is to be made by an observer.

(b) Theodolite, Mark I.—Sight the telescope towards the sky and adjust eye-piece. Focus until a clear image of the graticule is visible; next sight the instrument on to a distant object which can be focussed by means of the eye-piece and graticule together as one unit.

2. **Sights**

Using the open sights S, direct the telescope on to a distant object. If on looking through the eye-piece this object is not approximately in the centre of the field, then the sights are to be adjusted until this condition is fulfilled.

3. **Slackness in Tripod and Levelling Screws.**

Sight theodolite on to a distant object, and lock the horizontal and both vertical axes. Grip tribrach firmly (**not the telescope**) while looking through the eye-piece. Put a very gentle strain on the tribrach, first to the left and then to the right. The object should return to its original position in the field after each strain. If not, there is slackness either in the tripod or levelling screws. If, after tightening tripod nuts and levelling screws, this slackness persists, the instrument should be reported as unserviceable.

4. **Bubble Level**

The bubble may not be parallel to the horizontal circle—

(a) Rotate theodolite in azimuth about the **observation** axis until the bubble is parallel to the line joining two of the levelling screws. Centre bubble by means of these two screws.

(b) Rotate the instrument through **180°**. If the bubble is now not in the centre, correct half the error by the capstan head screw at one end of the level and half by the same two levelling screws used in step (a).

(c) Repeat for (a) and (b) until bubble remains central in the two positions.

(d) Turn instrument through 90° from (a) and use the third levelling screw to centre the bubble. The bubble should now remain central while the instrument is slowly rotated through 360°.

5. **Coincidence of Vertical Axes**

There are two vertical axes of rotation, as follows:—

(a) **Orientation axis** is the one about which the instrument rotates when the horizontal circle is released and the horizontal tangent screw is engaged.

(b) **Observation axis** is the one about which the instrument rotates when the horizontal circle is engaged and the horizontal tangent screw released. This is the axis about which the theodolite rotates in azimuth when a balloon is being followed.

In a correctly adjusted instrument these two axes should be coincident. To test for the coincidence of these axes, first adjust the bubble for the observation axis as in (4) above, then lock the horizontal tangent screw, and release the horizontal circle so that the instrument can rotate around the orientation axis. Slowly rotate the theodolite through 360°, and if the bubble shifts appreciably from the centre, the axes are not coincident. No adjustment is provided for this and, if defective, the instrument is to be reported as such.

6. **Lost Motion in Tangent Screws**

Sight the theodolite on to a distant object and lock the axes of rotation. Test for lost motion in azimuth tangent screw by slightly turning to and fro the azimuth vernier. If there is any free movement of the vernier drum there may be slackness either in the pivot points, tangent screw thread, or in the azimuth tangent screw bearings. The latter are not adjustable, but the former can be adjusted by slackening off the ring nut and tightening the pivot, then tightening the ring nut again. If slackness persists after this, then no further adjustment can be carried out, and the fact should be reported and a replacement obtained.

Test similarly for elevation tangent screw.

7. **Vernier Tests**

Vernier should read zero when the corresponding observation window reads whole divisions.

(a) Adjustment for **Single Telescope** Theodolite:—Loosen appropriate capstan locking nuts on sides of tangent screw box. Set vernier to read zero and with two screwdrivers—one in each pivot—move the tangent screw until the main scale reads whole divisions. The screwdrivers must be moved so that as one screw comes out the other goes in. After adjusting, tighten the capstan locking nuts.

The azimuth pointer 90° from the eye-piece should agree in this respect with the pointer under the eye-piece. Two screws are provided on this pointer for this adjustment.

(b) **Mark I.**—Set the main scale on whole degree and hold vernier drum securely and slacken screw in centre of it. Pull vernier drum away from tangent screw and rotate until reads zero. Push back and tighten central screw. This cannot be done on station, however, as special tools are required, without which the adjustment must not be attempted.

8. Horizontal in Telescope Bearings

The telescope axis bearings (horizontal axis) must be horizontal. To test, first accurately level the theodolite, then set the telescope to a clearly defined point X at an elevation of 45° or to an object as high as possible. By means of verniers, bring this object to the centre of the graticule.

Depress the telescope as far as possible and note the point Y coinciding in the field of view with the centre of the graticule.

Rotate the telescope through approximately 180°, transit and re-direct the telescope at this lower point Y. Then elevate the telescope to the original point. If the graticule again intersects **to the point X, then the transit axis is horizontal. If not, the** instrument is out of adjustment. If the error is so small as to be inappreciable, it may be disregarded. For a larger error, the instrument is to be returned for adjustment.

The adjustment is carried out by the capstan headed screw on bearing C of telescope on the single telescope type, but, under no circumstances, should any adjustment be attempted.

9. Horizontal Collimation of Telescope.

The line of collimation of the telescope should coincide with the transit axes of the theodolite. Often it will be found to be displaced from this position either in a horizontal or vertical direction.

Caution: Before testing for horizontal collimation, it is necessary to check the graticule. To test, sight the telescope on a distant object and move elevation vernier. The object should move along the vertical line. If adjustment is needed, the graticule may be rotated by slackening the four diaphragm screws.

To test for horizontal collimation, after carefully levelling sight the theodolite on a distant object at low elevation and note the point coinciding with the vertical line of the graticule. Rotate the theodolite through **exactly 180°** in azimuth and transit. If the vertical line intersects the same point, the collimation is correct. If not, correct half the error by shifting the graticule horizontally by means of the diaphragm screws H (using the pair that are horizontal when the telescope is horizontal), and half by means of the azimuth tangent screw.

Then rotate through **exactly 180°**, transit, and the same point should now coincide with the centre line of the graticule, or very nearly so. Repeat until the adjustment is correct.

If the error detected is considerable, it is advisable to check (8) again before altering the diaphragm screws.

10. **Vertical Collimation of the Telescope**

Accurately level theodolite and sight on to a distant object at as high an elevation as possible. Take readings and then transit telescope and sight again on to the same object and read the elevation, remembering that this time the scale is read the opposite way and thus the vernier reading must be subtracted from the scale reading. (If the scale reading is 22° and the vernier reading 7 the elevation is 21·3°.) The error, if any, is half the difference between these readings. To correct, set the elevation to the mean of the readings and by means of the two **vertical** (or nearly so) graticule screws move the graticule until the **horizontal** line of the graticule is coincident with the object.

If the error is greater than 3 graticule divisions it cannot be corrected by moving the graticule and an error in the index pointer on the elevation scale is indicated.

This adjustment should be carried out in conjunction with (9) and both adjustments should be checked when either has been altered.

Any errors that persist are probably due to prism shift and should be immediately reported.

11. **Theodolite Mark I**

Coincidence of Focal Planes of Two Objectives.—A small capstan screw controls the position of the swinging mirror and this may be adjusted until coincidence is obtained. This must **not** be attempted on station.

SECTION 8

UPPER AIR EQUIPMENT

Hydrogen (G 268/482)

Hydrogen is supplied compressed in steel cylinders. As the initial pressure of the gas is very high—about 120 atmospheres or 1800 lbs. per square inch—the hydrogen cylinder should be regarded as a potentially dangerous article and should be treated with care. The cylinders are fitted with a top cap which fits over the main valve. Cylinders should be kept in a shaded place. It should be remembered that hydrogen is **highly inflammable,** and, when mixed with air, **highly explosive.** Hence **no naked lights should be taken near stored hydrogen.**

The Fine Adjustment Valve (G.268/5185)

A fine adjustment valve is provided to control the flow of gas. The fine adjustment valve must be removed from each cylinder as it becomes exhausted and attached to the fresh cylinder. It should be remembered that the fine adjustment valve has a **left-handed thread,** so that normal screwing-up motion is required to unscrew the valve and vice versa. The sealing gasket in the fine adjustment valve should be in good condition so as to ensure a gas-tight joint.

When filling a balloon the fine adjustment valve should be given a small opening and the main valve then opened. When starting on a new cylinder the initial **fine adjustment valve opening must be very small,** as otherwise the high pressure will blow the connection tube off the balloon filler. As a cylinder becomes more exhausted a larger valve opening moy be used.

When shutting off the hydrogen the **main valve must be shut first** and then the fine adjustment. If this practice is not followed there is a tendency for the fine adjustment valve to be shut first and the main valve forgotten. This may result in much loss of gas due to the fine adjustment valve joint not being gastight.

Balloons.

The following balloons are issued:—

Approx. Weight	Vocab. No.	Inflated Circum.	Colour
80 gm.	G 268/5019	150 inches	White; black; red.
30 gm.	G 268/58	90 inches	White; black; red.
20 gm.	G 268/5018	70 inches	White; black; red.
10 gm.	G 268/5017	48 inches	Red; black.

The object of the different colours being used is to provide maximum visibility against various types of background.

White balloons are for use against a blue sky background, and black balloons against a cloud background. Against a clear sky in the early morning just about sunrise, however, a black

balloon will be found more suitable than a white. With a mixed sky, i.e., half blue, half clouded, a red balloon can be used. If a red is not available a black balloon will be found preferable to a white.

BALLOON FILLERS

Balloon Filler—Type 1 (G 268/5092)

Description.—This filler is designed for filling balloons with free lifts ranging from 0 to 1,000 grams. The fitting to which the balloon is attached will cover a wide range of neck sizes.

The instrument consists of a brass base plate with standards, a combined beam and filling tube. Steel knife edges on the beam rest in V-shaped bearings in the brass standards. A brass scale is graduated from 0 to 12 with 10 minor divisions to each major division. A valve is provided to restrict back flow of hydrogen when rubber tube is disconnected.

Alternative sliding weights are provided, the larger weight covering the range from 0 to 1000 grams and the smaller weight covering the range 0 to 120 grams. Two counterpoise weights are used to balance the filler for the required range.

A protecting cap is provided for the valve.

Use

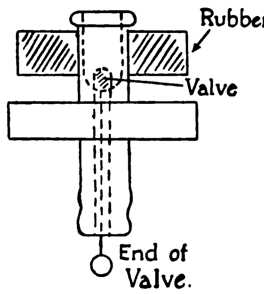
(a) For filling balloons to a free lift within the range 0 to 120 grams: First place the beam on the standard. Place the smaller weight on the scale so that its left-hand edge is in line with the "0" graduation. Adjust the position of the counterweight until the beam is balanced horizontally; attach the balloon to the fitting. Connect the gas supply tube to the filler. Slide the weight to such a position that the free lift desired is indicated by the left-hand edge of the weight against the scale. (The numbered graduations have the values 0, 10, 20......120 grams.)

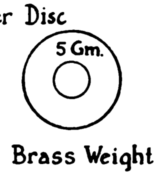
Fill the balloon until the beam passes just through the horizontal position. Disconnect the rubber tubing from the valve and release gas by means of valve until an accurate balance is obtained. The beam should now be removed from standards to facilitate tying and detachment of balloon.

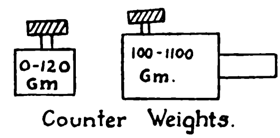
Caution.—When setting counterweight ensure that retaining set screw does not foul the brass standard.

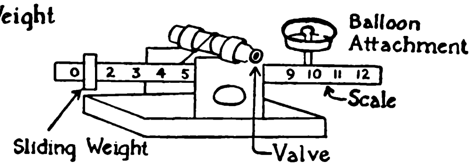
(b) For filling balloons with free lift between 120-1000 grams. Replace small sliding weight with large one and the small counterweight with the large one (this goes on the same end of the tube as the ballon fitting). Place beam on supports and after setting sliding weight with its left-hand edge on zero, adjust the counterweight for balance. Then fit balloon and inflate, after setting sliding weight.

With this large weight in use the numbered divisions on the scale have the values 0, 100, 200........1100 grams which caters for any balloon manufactured.









Balloon Filler Type 2.

Balloon Filler Type I. [G 268/5092]

Balloon Filler—Type 2

This is made of aluminium and has a check valve to prevent back flow of gas. It weighs 22 grams and separate weights are provided to enable any required weight to be obtained. A large rubber disc is used to fit the neck of the present type of balloon and the weight of this rubber disc must be taken into consideration when determining the weight of the filler.

To use the filler the balloon is attached to the rubber disc and the other end of the filler attached to the rubber tube from the hydrogen cylinder.

The balloon is filled until it can just float in the air while the filler is attached—its free lift will be then equal to the weight of the filler.

When trying the balloon for free lift a piece of cotton should be tied to the valve and held to prevent loss if the balloon should accidentally get away.

Free Lift of Balloons

From a table supplied the following free lifts will be noted:—

Weight of balloon	Vocab. No.	Ascending velocity	Free lift
30 gm.	G 268/58	150 metres per min.	68 gm.
20 gm.	G 268/5017	150 " " "	58 gm.

When a tail or lantern is attached the weight of the tail or lantern is added to that of the balloon, and the balloon is assumed to be of that combined weight.

Example: Suppose a 10-gram lantern is attached to a 30-gram balloon. From the chart find the lift for a 40-gram balloon—76 grams for 150 metres per minute.

Now fill balloon (a) **with lantern attached** to give free lift of 76 grams or (b) as is more convenient **without lantern attached** to give a lift of 86 grams.

Storage of Balloons

Balloons should be kept in a cool dry place. If the balloons are well chalked it prevents deterioration.

In the tropics the high temperatures and humidity tends to cause rapid deterioration. This is prevented by storing the balloons in a special cabinet which has a shallow tray of turpentine in the bottom. The balloons are placed on a grid above the turpentine. The vapour of the turpentine prevents deterioration of the balloons.

Tails

If a tail is to be used the length of the tail must be 12 metres from centre of balloon to centre of pendant. The pendant on the end of the tail is formed by folding a sheet of paper into cylindrical form. Standard size sheets of paper are provided for tails. It is necessary to attach a second small sheet of paper half-way down the tail for the first readings, as the full tail is generally too long to read on the graticule at the first minute. Longer tails, e.g., 36 metres, can be used if desired to obtain tail readings at greater distances, suitable intermediate pendants being attached for the first few readings.

Lanterns (G268/140)

The small paper lanterns supplied weigh 6 grams which, with half an inch of candle, 6 grams, makes a total of 12 grams. The lantern is suspended about 3 feet below the balloon by a length of thread.

Prismatic Compass (G6E/291)

(a) **Survey type.**—In this instrument a magnetised steel compass needle is pivoted in a flat circular brass case, fitted with a glass top. The compass needle carries a light circular compass card of cardboard or aluminium graduated in degrees and fractions (usually thirds) of a degree. Attached to one side of the case is a vertical sighting wire and diametrically opposite is a rear sight through which the sighting wire is observed and which carries a right-angled reflecting prism which enables the horizontal compass card to be viewed at the same time as the vertical sighting wire.

When not in use the sights fold down and a protective brass cover is placed over the glass top of the compass.

To obtain the magnetic bearing of an object the compass is held horizontally at eye level and the sights aligned on the object. The front sighting wire will appear to cut the scale which is seen simultaneously by means of the reflecting prism. The reading

where the sighting wire of the front sight appears to cut the scale gives the bearing required.

It will be noted that, since the compass card is read at the rear sight, the scale must be numbered accordingly. Thus the North end of the compass needle corresponds with the 180° marking and the South end with the 360° marking. The figuring is also printed inverted and reversed to allow for the inversion and reversion which is involved in the reflection in the prism.

(b) **Aircraft Type.**—This instrument in a refinement of the above and the needle is mounted in a chamber filled with alcohol. It is "dead beat" in action and very steady. It has only one sight, below which is a prism which enables the scale to be read as the object is sighted. The North end of the needle is marked 360°.

To use, it is held at eye level at arm's length and the prism adjusted to show the scale. Care must be exercised because each division of the scale is 2°.

Compass Variation

It is well known that a magnetic compass does not point true North, but indicates what is known as Magnetic North. The angle between the magnetic meridian and the true geographic meridian is known as the Compass Variation or the Magnetic Deviation. The variation differs at different parts of the earth's surface and also undergoes periodic changes. On page 19 of A.O.H. is a chart showing the Isogonal lines (lines joining places having the same magnetic declination) for the Australian region. We see that at Melbourne the variation is about 8° East of true North At Perth it will be seen that the variation is about 5° W.

To Determine True North with the Prismatic Compass

To determine true North the variation must be taken into account, e.g., suppose the variation at the given locality is 9° E. This means that the magnetic compass points 9° E. of true North. Hence true North is given by a magnetic bearing of 351°. Thus to find true North find an object whose bearing on the prismatic compass is 351°.

If the variation at the locality were 5° W., then true North would be given by a magnetic bearing of 5°.

FREE LIFT OF PILOT BALLOONS

Weight of Balloon.	Rates of Ascent. Metres per Minute.		
Grams.	100 m./min.	125 m./min.	150 m./min.
	Grams.	Grams.	Grams.
10		22	47
12		24	49
14		26	52
16		27	54
18		29	56
20	15	30	58
22	16	31	61
24	17	32	62
26	17	34	64
28	18	35	66
30	19	36	68
32	20	37	69
34	20	38	71
36	21	39	72
38	21	40	74
40	22	42	76
42	23	42	76
44	23	43	80
46	24	44	81
48	25	45	82
50	25	46	84

Above table based on Dines Formula: $V = 84 \dfrac{L^{\frac{1}{2}}}{(W + L)^{\frac{1}{3}}}$

V = Rate of ascent metres/min.
L = Free lift in grams.
W = Weight of balloon in grams.
84 = Constant.

Free Lift for Darex No. 100—Pilot Balloons.

Average Weight of Balloon—100 grams.

Free Lift—550 grams.

Resulting from the difficulty of transporting cylinders of hydrogen to distant and inaccessible stations, a form of hydrogen generator has been developed.

It is a steel cylinder, much like an ordinary hydrogen cylinder but with a large screwed plug enabling the contents to be removed and the cylinder cleaned before recharging, and a valve assembly which consists of an outlet valve, pressure gauge and safety plug.

There are two sizes of generator - a large one, Type A, Ident No. G.268/5254, producing approximately 100 cubic feet of hydrogen, and a small one, Type B., Ident No.G.268/5255, producing about 50 cubic feet of hydrogen. Except for the cylinder any part may be interchanged in either type.

The generators are charged with ferro silicon, sodium hydroxide(caustic soda) and water.

Ferro silicon (Fe Si) is an alloy of iron and silicon and looks like galena or, when finely powered, graphite. It is supplied in packages of 2 lbs. of various grain size.

Sodium hydroxide(Na OH) is in powdered form and is supplied in containers of $2\frac{1}{2}$ lbs. These being the quantities required to recharge the small generator, Type B, (double quantities are used in the large one, Type A.)

The reaction is probably of the form -

Ferro Silicon + sodium hydroxide + water =

sodium silicate + ferrous hydroxide +hydrogen.

$$Fe\,Si + 2\,Na\,OH + 3H_2O = Na_2SiO_3 + Fe(OH)_2 + 3H_2$$

/but.....

but temperature determines whether normal silicate or higher silicates form.

Each generator is supplied with a bucket, a funnel, cleaning rod, special duplex spanner and a pair of goggles, as well as a special stand. The goggles are to be worn during the recharging procedure to protect against splashing of the caustic soda.

The steps to recharge a generator are as follows:-

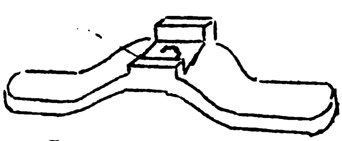
1. Open valve to allow escape of residual gas.
2. Slacken setscrew in centre of plug about one turn with the special spanner.
3. Push spanner down onto plug and unscrew it.
4. Remove rubber washer and clean it.
5. Clean plug, oil threads and place on one side.
6. Remove valve assembly from cylinder.
7. Wash valve assembly to remove any grit by
8 forcing water through outlet.
8. Empty contents of cylinder into bucket and dispose of same.
9. Wash cylinder out and remove any solid residue. If a hose is available invert cylinder, place bucket to catch outflow and use full pressure. The residue is generally soluble in water thus if residue is sticky or difficult to remove add about a gallon of water and allow to stand for several hours, or if possible, overnight.

10. Place correct quantity of caustic soda in the bucket and dissolve in water, stirring all the time to ensure complete solution of caustic soda. If stirring is neglected large insoluble lumps are produced which will impair the efficiency of the generator. Finally fill bucket to the ring spun in the side.

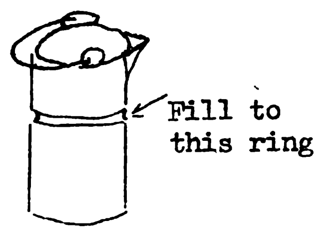
11. Replace valve assembly and open valve.
12. Secure cylinder in inclined position in frame insert the rubber sealing ring and funnel.

13. Pour in approximately half of caustic soda solution.
14. Add the required quantity of ferrosilicon
15. Pour in remainder of caustic soda solution.
16. Remove funnel and insert plug.
17. Screw plug up with spanner and when tight lift spanner clear of plug and tighten centre setscrew.
18. Close valve.
19. Wash all utensils and put away.
20. Wash cylinder down to remove any caustic soda from the neck.

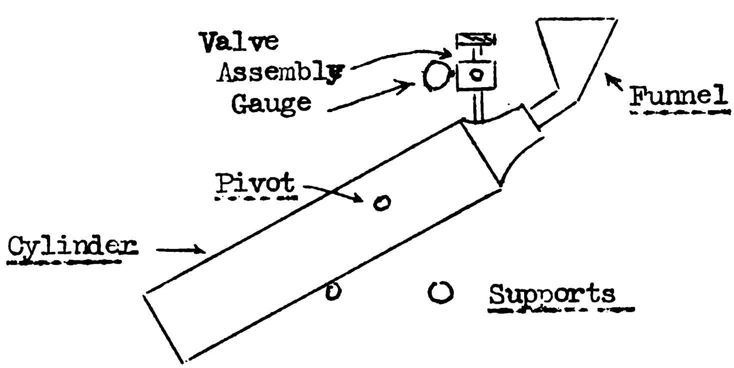
A short time (about 5-7 minutes) will elapse before any action becomes apparent, depending upon the size of the ferro silicon and the temperature of the caustic soda solution. Powdered ferro silicon reacts very quickly and vigorously and it may be necessary to hose the cylinder down to prevent the temperature raising the pressure above that which will blow the safety plug (2,700 lbs. per square inch).



Spanner.
Centre fits locking screw
Outside fits plug.

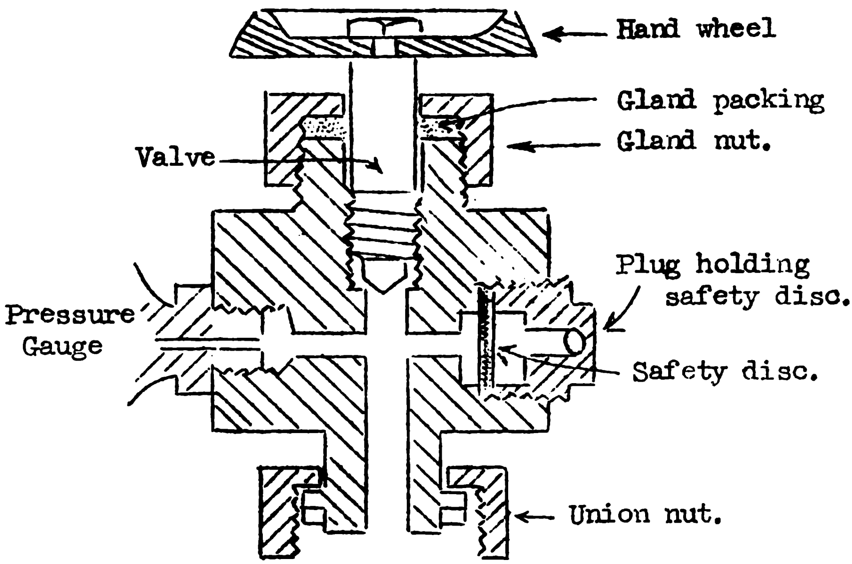


Bucket

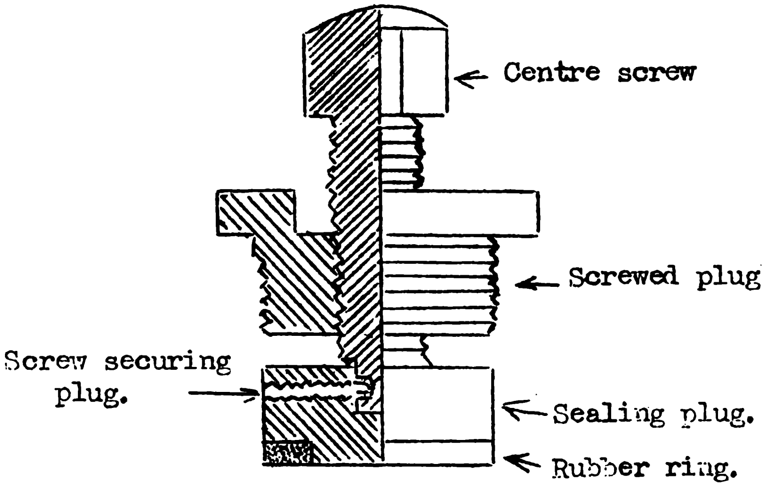


Filling Position

SECTION OF VALVE ASSEMBLY



Section through plug.



SECTION 9

ANEROID BAROMETER

The aneroid barometer is an instrument which, while not susceptible of the same high order of accuracy as a mercury barometer, is a good substitute for the latter under conditions where the use of a mercury barometer is not admissible. Its operation depends in principle on the fact that a thin metal disc or membrane responds elastically, to an appreciable degree, to the difference of pressure on its faces.

Fig I.

CONSTRUCTION OF THE ANEROID CELL

In Fig. 1 is shown a diagrammatic sketch of the essential parts of an aneroid cell. B is the base plate to which the aneroid mechanism is attached. C is a corrugated chamber formed by two thin metal diaphragms, about 0·005 inch in thickness, called the vacuum-box, since it is thoroughly exhausted of air. The corrugations produce greater flexibility of the membrane. It is securely bolted to the base plate B at the centre of the lower diaphragm. S is called the control spring and its function is to prevent the collapse of the box when exhausted. As the upper diaphragm moves with changing pressure, the movement is transmitted to the arm A, which is connected to a lever system and an indicating dial.

COMPENSATION OF THE ANEROID FOR TEMPERATURE

The effects of temperature on the mechanism of an aneroid barometer are sufficiently marked to necessitate compensation in aneroids generally. Changes in temperature affect different parts of the mechanism in different ways, and the nett result of an increase in temperature is to make the diaphragms of the box approach one another. Two methods are employed in practice to compensate aneroids for temperature changes. The compensation, however, is limited to a comparatively small range of temperature.

(i) The better method is to make the long arm of the lever system of the two metals, viz., brass and iron firmly brazed together. Actually the arm is chiefly of

brass, but a length of iron is inserted in the upper side. Now the thermal expansivity of brass is greater than that of iron, so that an increase in temperature results in the lever arm bending slightly concave upwards. This opposes the tendency of the diaphragms to approach one another.

(ii) The more widely used method, however, is to leave a small amount of air in the vacuum-box. The effect of an increase in temperature will be therefore to increase the pressure within the box and thus tend to make the diaphragms move further apart. By a suitable choice of the amount of air this tendency to move outwards can be made to exactly equal the tendency to inward movement due to the thermal expansions in the box itself, over any given range of temperature.

The accuracy obtainable from an aneroid barometer is of a lower order than that given by the average mercury barometer. Although an aneroid is sensitive to quite small changes of pressure, its reading cannot be relied upon to give the absolute value of the pressure to a high degree of accuracy. It is very useful, however, as a relative pressure indicator, giving an accuracy of $\pm$ 0·01 inch for a change of pressure under good condition.

The utility of the aneroid as an absolute pressure indicator is limited by gradual and appreciable changes in the internal structure of the metal of the vacuum box. This defect is generally known as "creep." Other sources of error are friction of the mechanism and hysteresis. The stiffness of the elastic system including both the spring and the vacuum box, is chosen with a view of reducing the effects of "creep" and hysteresis to a minimum.

In the barograph, or self-recording barometer, a number of cells were used to increase the sensitivity but it is readily seen that to obtain high accuracy all the cells must be identical in construction. A method now used employs a single cell constructed as shown in Fig. 2, which gives the increased sensitivity and no matching of cells is required.

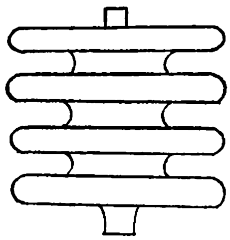


Fig. 2

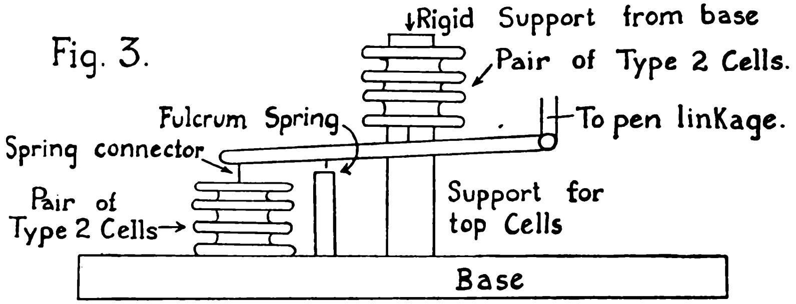
As the motion of the top of the cells is not a linear one, a link motion is introduced to give a linear movement of the pen.

The new type of micro barograph (G268/5025) consists of two pairs of matched cells of the type shown in Fig. 2. They are arranged as indicated in Fig. 3, one pair on each side, one above, one below, of the fulcrum of the lever. The resultant effect is

to magnify any pressure change. Flexible spring bearings are used to overcome friction and the slotted link device to obtain linearity and adjustment.

The scale covers a range of one inch, 0·5 inch either side of a zero line. Only changes in barometer pressure are indicated as the instrument should be set to zero each day.

Fig. 3.



THE PAULIN ANEROID (G 268/5042)

The usual type of aneroid is always subject to errors due to lag, as frictional resistance is unavoidable. With the Paulin aneroid readings can be taken immediately after any change of pressure or height without having to wait for the "lag effect." The accuracy of the Paulin is claimed to approach that of precision mercury barometer, due to its qualities of minimum elastic hysteresis and very low temperature coefficient.

PRINCIPLE OF THE PAULIN ANEROID

The principle of the Paulin aneroid may be compared with that of a balance. The object to be weighed is the pressure of the atmosphere. The weights of the balance are replaced by two tension springs. One of these springs exerts a constant pressure, the other spring can be given varying tensions and it is by varying the tension of this spring that the beam of the balance is brought into its equilibrium position under different atmospheric pressures. Diagramatically it is represented thus:—

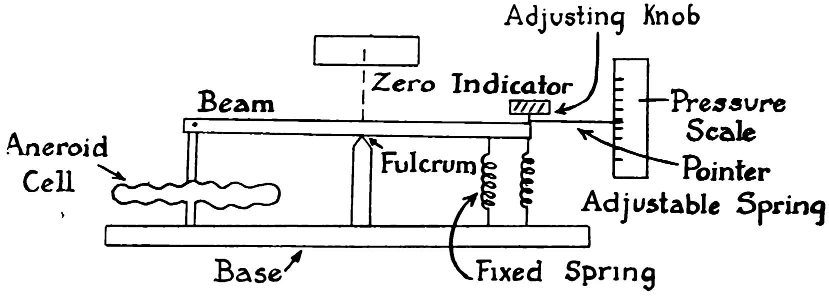


Fig. 4.

The pressure is indicated by a pointer rotating over the usual circular scale. This pointer is operated not by the motion of the aneroid cells but by the mechanism which changes the tension of the balancing spring. This is done through a cam system operated by turning the knurled knob in the centre of the dial to which the pointer is attached.

The fixed spring which is at almost constant tension is also used for temperature compensation, the actual adjustment of which is very difficult but effective. The final position of the larger pointer, which moves over the graduated dial, is determined by the adjustment of a fine needle pointer to the zero position marked on a mirror on the outer edge of the main scale.

The essential point to remember is that when a reading is being taken after adjusting the tendency pointer, the aneroid membranes are always in the same position, not in a distended or compressed position, as is normal with the ordinary aneroid.

The procedure to observe the pressure is, therefore, as follows:

(i) Turn the knob in the centre of the dial which regulates the spring tension until the balance beam is in its equilibrium position. This is so when the "tendency pointer" on the edge of the dial is over its zero mark.

(ii) The indicator pointer now indicates the pressure, or in the case of a surveying or altimeter type, both pressure and height.

SECTION 10

WIND DIRECTION AND VELOCITY

Measurement of Direction

It is now common knowledge that wind direction is not constant but that short period changes of a few degrees occur. A wind vane, therefore, must be constructed such that it has a small moment of inertia and a fairly large control surface to show up the small fluctuations.

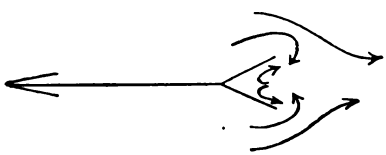


Fig 1.

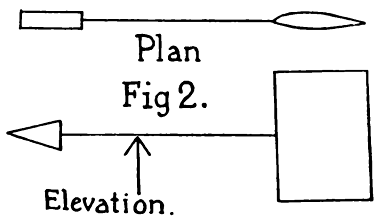


Fig 2.

The original design employed a splayed tail (Fig. 1) but this was found to be inaccurate, due to eddies which set up oscillations. The modern idea is to use a streamline section which does not disturb the stream motion of the air (Fig. 2). But the weight must be kept low to reduce the moment of inertia, and therefore the tail is made hollow. To get good control the point of the support must be well away from the tail. If the support is not at the centre of gravity, the heavy end will tend to sink to its lowest position and so the tail must be balanced by a weight at the other end.

The torque of the new type is eight times that of the old type and both types are the same weight.

The following points must be watched in the design:—

N.B.

(a) No friction, i.e., ball thrust race.
(b) Vane must be balanced about its pivot.
(c) Vane must give maximum torque possible if it is to turn a recording instrument.
(d) Vane must not interfere with free flow of air or it will oscillate due to formation of eddies.

Measurement of Velocity

There are three main types of instrument in use for measuring wind velocities:—

(a) Cup or Fan Anemometer;
(b) Pressure Plate Anemometer;
(c) Pressure Tube Anemometer.

(a) Cup Anemometer

The cup anemometer usually consists of four hemispherical cups attached to the ends of two crossed metal arms. The cross is pivoted at its central point in such a way that it is free to rotate in the horizontal plane. The difference of pressure of the wind on the convex and concave surfaces of the cup causes the cross to spin round. The number of revolutions of this cross may then be used to measure the wind travel, and, if the number of revolutions in a given time be measured, the average value of the wind speed can be obtained. This, however, will not give short period changes.

The first instrument made by Dr. Robinson had only two cups, but this was found to be unsatisfactory owing to heavy pulsations. So another arm was added and for this anemometer Robinson found by experiment that the run of the wind was approximately three times the linear run of the centres of the cups. (The ratio of the distance travelled by the wind to the distance travelled by the cups is known as the "factor" of the anemometer.) By suitable gearing to a revolution counter, therefore, the motion of the cups can be made to give a direct reading of the wind travel.

Tests at the National Physical Laboratory in a wind tunnel showed that the factor was somewhat less than 3 and also that it was not constant but varied with the size of the anemometer and the value of the wind velocity. For the Beckley Cup Anemometer with 9-inch cups and 24-inch arms, the accepted factor is 2·2. Another standard pattern has 3-inch cups and 7⅜-inch arms, and for this instrument a factor of 2·73 is adopted.

The errors introduced by the use of a constant factor are illustrated in the following table for the latter type of instrument.

Indicated speed (m.p.h.)	1	2	4	6	8	10	18
True speed (m.p.h.)	1·2	2·3	4·5	6·4	8·3	9·9	15·8
% Error (of the true speed) . .	—17	—13	—11	—6	—4	+1	+14

It was found that more consistent results were obtained by using three cups instead of four. The large inertia of this type of anemometer renders it unsuitable for recording short period fluctuations in wind speed commonly known as gusts. Friction at the bearings is often also responsible for errors. Cup type anemometers require a finite wind velocity to start them, and thus do not register light winds. They usually indicate a mean velocity which is above the true mean velocity.

The American Type

In this type, the shaft which is rotated by the movement of the cups is connected directly to the rotor of an A.C. generator.

The voltage generated is a common factor of the speed of rotation, and, therefore, wind speed may be accurately measured.

Two advantages of this type are that it gives a direct reading of the wind velocity, and the factor is automatically corrected during calibration, eliminating the error due to the use of a constant factor. It can also be easily made distant reading and self-recording if desired.

The Fan Anemometer (G 268/5015)

The principle of the fan anemometer is very similar to that of the cup type, except that a light fan is used instead of the cups, and is mounted so as to rotate about a horizontal axis. The most common form is that of the air meter which is described in A.O.H., page 82, in which the run of the wind in feet is obtained for a given time—usually half or one minute. Thus the velocity can be obtained.

(b). **Pressure Plate Anemometers**

These were constructed in an attempt to measure gusts, but were found to be inaccurate due to eddying. In one type (Fig. 1) the pressure was determined by a spring. Another type (Fig. 2) attempted to measure the wind velocity by the displacement of a plate from the vertical, but the scale closes up rapidly with increasing velocity. Neither of these were found to be satisfactory and there is none in general use.

These anemometers must be put into direction of wind. Used as air speed indicators on old type planes.

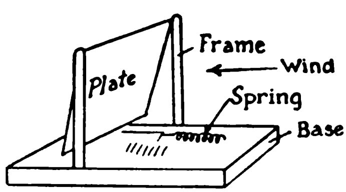


Fig 1.

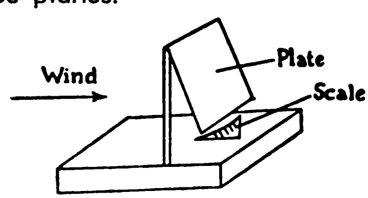


Fig 2

SECTION 11

PRESSURE TUBE ANEMOMETERS

1. **Float Type** (G 268/5006)

The Dines pressure tube anemometer records both the velocity and direction of the wind. It consists of four main parts:—

(a) The head.

(b) The transmitting gear.

(c) The velocity recorder.

(d) The direction recorder.

These parts will be discussed briefly here and for further information reference should be made to the B.O.H., pages 118-129, or the A.O.H., pages 83-87.

The head is so designed that it is free to rotate and will record the wind direction. The end facing into the wind is hollow, thus allowing the pressure of the wind to increase inside the tube and the increase in pressure is transmitted by composition pipes to the velocity recording apparatus. The fixed part of the head has four rows of holes on the outer tube. Wind blowing past the head lowers the pressure causing suction through these holes, and this negative pressure effect is applied to the space above the float in the float chamber by medium of a composition tube.

The composition tubes comprise the velocity transmitting gear, and a number of duralumin rods, fastened together by brass units, are rigidly attached to the moving portion of the head and the direction recording gear. The whole head assembly and tubes are supported by a steel mast and stays.

The velocity recorder is a specially designed float which is placed with open end downwards in a tank partially filled with distilled water. The pressure tube is connected to the inside of the float through a stop cock and a hollow brass tube projecting from the base up the centre of the tank. The float has a roller attached which slides in a vertical groove on the inside of the tank so that the float cannot rotate. The suction tube connects with the inside of the tank above the surface of the water and so lessens the pressure above the float. The suction and pressure effect is, therefore, combined to raise the float and give recordings of velocity. The motion of the float is transmitted to a pen by means of a stem passing through an almost air-tight collar.

When the surface of the water in the tank is level with the pointer on the outside of the tank, the adjustment of the balance of the float is made by placing more or less shot in a specially provided cup attached to the float rod until, with both taps turned off, the pen will slide smoothly to zero velocity after raising and releasing. On no account should the float rod be oiled or touched with the fingers, and only smooth graphite should be used for cleaning the rod. A most important consideration in the design

of these recorders is the fact that, whereas a record of wind speed is required, the pressure difference between the inside and the outside of the float is proportional to the square of that speed.

Arrangements must, therefore, be made for the lift of the float above the position of equilibrium to be proportional to the square root of the difference of the pressure in the two tubes. This is secured in the Dines by fashioning the shape of the float to give the required lift for each pressure difference. The float must compensate for rapid increase of pressure with velocity increase and, therefore, the effective area must decrease as it lifts.

The duralumin rod attached to the moving portion of the head is connected to the direction recording arms through a universal joint and a clutch. When the clutch is released the cam system can be moved in either direction without moving the wind vane; this enables the direction pens to be adjusted so that they will both read north at the same time.

Instructions for the care, maintenance and adjustments of the instrument will be found in the B.O.H. and these should be carefully studied in addition to those given here.

ROUTINE MAINTENANCE OF DINE'S ANEMOGRAPH

A. **Chart Changing**

(1) Close both stop cocks and note exact time.

(2) Allow velocity pen to come to rest. (If air is calm at moment of closing stop cocks, displace the float slightly to leave a vertical time mark.)

(3) Rotate the clock cylinder slightly so that all pens mark their resting points on the chart.

(4) Swing the three pens away from the paper by means of the pen lifter.

(5) Remove the completed chart from the drum.

(6) Place a blank chart in position, taking care—

(a) that the new chart be not folded, creased, or crumpled in any way before use;

(b) that the ends of the two long horizontal lines which are carried to the edges of the chart overlap;

(c) that the bottom edge of the chart is resting on the flange of the drum. If the edge of the chart is not cut exactly parallel to the horizontal lines on the chart, it will not be possible to place it on the cylinder so that the edge touches the flange throughout its length; and

(d) that the paper fits closely to the cylinder.

(7) Swing the two direction pens into contact with the paper. One pen will indicate the wind direction and the other should rest on one of the N. lines.

(8) If necessary, raise or lower the clock drum by means of the middle knurled screw inside the drum until the upper or lower pen is exactly on the upper or lower N. line respectively.

(9) Swing the velocity pen into position. If the velocity pen is not indicating zero velocity, then adjust the height of the velocity pen by the screw adjustment in which the pen is placed until this condition is satisfied.

(10) Now rotate the drum until the velocity pen is indicating correct time. If the direction pens do not then indicate correct time, adjust by means of the pivot mountings at the extreme right-hand end of the direction arms. To do this place the finger and thumb of one hand over the brass ends of the pivots of the appropriate direction arm and with the other hand loosen the knurled screws holding the pivots in position and slide the direction arm across until the pen indicates the same time as that indicated by the velocity pen.

Caution: When making this adjustment, make sure that there is no slack between the pivot points; but excessive pressure is not to be present.

(11) Wind clock by moving external lever backwards and forwards; clocks are provided with eight-day movements.

(12) Open stop cocks.

B. **Cleaning Pens**

(1) Remove the faulty pen and soak in methylated spirit. It may be necessary to adjust the pen travel after pens have been removed. This adjustment is given below.

C. **Adjust for Float Position**

(1) Adjust tank cover to perfectly level position by means of levelling screws provided.

(2) With float resting on bottom of tank, water level should be exactly on pointer tip in gauge glass.

(3) Turn off both stop cocks.

(4) Displace float slightly. The float should slowly settle without hesitation until mark on float rod is exactly level with brass collar on top of tank. Shot weights are provided to perfectly balance the float in this position. (This adjustment is made with the velocity pen in position.)

D. Adjustment of Direction Pens

(1) Disconnect the clutch so as to free the direction cams from the dural rod connecting to the head.

(2) Rotate helix and observe motion of pen arms. If the top pen rises or the bottom pen falls too rapidly or too slowly when approaching their respective datum lines, the balancing weights should be adjusted to prevent shock or uncertain motion.

Movements of the cams in and out can be made easy or stiff by loosening or tightening the cam pivot screws. The depth of engagement of a cam is adjusted by means of the set screw making contact with the end of the plate carrying the cam. If the depth is too great, the movement of the helix will be stopped at certain points. If not sufficient, the cam will not engage in the helix and there will be a loss of record.

(3) Remove the lower direction pen.

(4) Rotate the helix in a counter-clockwise direction and adjust screw holder of upper pen until this pen just reaches the lower N. line on the chart at the lowest point of its travel.

(5) When the pen has reached the top of its travel and its direction arm is resting on the dead stop, adjust the stop until the pen is on the upper N. line.

(6) Replace the lower pen and remove the upper pen.

(7) Rotate the helix in a clockwise direction and adjust the screw holder of the lower pen until the pen just reaches the upper line at the highest point of its travel.

(8) When the pen has reached the bottom of its travel, and its direction arm is resting on the dead stop, adjust this stop until the pen is on the lower N. line.

(9) Check movement to make sure there is no lost period in change over from one pen to the other.

(10) Engage clutch.

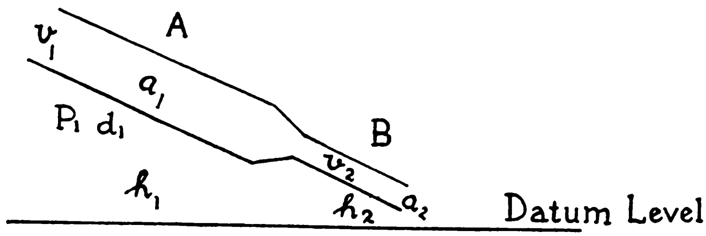
E. Orientation

(1) With an assistant holding the vane on the mast head in a true North and South direction, release the direction rod above the universal joint and rotate the helix until both pens indicate North. Then tighten screws on connecting coupling.

THEORY OF DINES ANEMOMETER

Bernoulli's Theorem

Consider an incompressible fluid flowing through a frictionless tube of varying cross section.



Let A and B be two points in this tube at heights h_1 h_2 respectively above a given datum level.

Let the values of the cross section of the tube, the velocity of the fluid, its pressure and its density, be denoted at A by a_1 v_1 p_1 and d_1, and at B a_2 v_2 p_2 and d_2 respectively; and let a_1 be $> a_2$.

Now since the fluid is incompressible, the volume V passing each cross section per second is the same,

$$\therefore a_1 v_1 = a_2 v_2 = V$$

$$\text{and since } a_1 > a_2 \therefore v_2 > v_1.$$

Consider the energy of two masses of fluid, each of this volume V at the levels A and B.

At A K.E. $= \frac{1}{2}d_1 V v_1^2$, and P.E. $= d_1Vgh_1$

and at B K.E. $= \frac{1}{2}d_2 V v_2^2$, and P.E. $= d_2Vgh_2$

The difference in energy between the mass at A and the mass at B must be equal to the work done in moving the mass from A to B against the pressure.

Therefore the work done equals $(p_2 - p_1) V$

$\therefore (p_2 - p_1)V = (\frac{1}{2}d_1Vv_1^2 + d_1Vgh_1) - (\frac{1}{2}d_2Vv_2^2 + d_2Vgh_2)$

But $d_1 = d_2$

$\therefore p_1 - p_2 = \frac{1}{2}d \ (v_2^2 - v_1^2) + dg \ (h_2 - h_1)$

If A and B are at the same horizontal level $h_2 = h_1$,

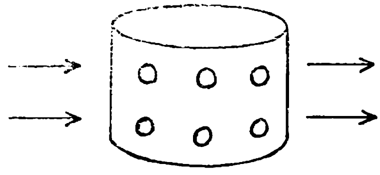
$\therefore p_1 - p_2 = \frac{1}{2}d \ (v_2^2 - v_1^2)$

but $v_2 > v_1$

$\therefore p_1 > p_2$

i.e., an increase in velocity produces a decrease in pressure. This is known as the Venturi effect and the principle is utilized in the Venturi water meter for determining the rate of flow of water through a pipe.

Consequently when air is flowing past, say, a perforated vertical tube, the air outside the tube has a greater velocity than that inside and consequently a smaller pressure.



Therefore the air flows out of the tube through the holes to equalize the pressure, producing a reduction in pressure within the tube (suction effect which is the function of the velocity of the air).

The Dines anemometer utilizes the difference between the pressure of the wind flowing in an open tube, and the suction caused by the wind flowing past holes in a vertical tube.

This pressure difference operates on a float which rises and falls as the strength of the wind varies.

When an open tube is placed in a current of air, there is produced inside the tube a pressure which differs from that outside by an amount which is proportional to the density of the air and to the square of its velocity, supposing that the current is brought to rest in the tube.

i.e., $p - p_s = kdv^2$
where p = pressure inside the tube,
p_s = static pressure of the air,
(i.e., the barometric pressure)
d = the density of the air,
v = the velocity of the air,
and k is a constant depending on the shape of the tube and the manner of presentation of its opening to the direction of the motion of the current.

In certain cases k is dependent on the velocity—in that at some critical velocity (usually about 200 m.p.h.) a rapid change in k will take place.

k may be made positive, negative or zero.

Case (1).—k is positive—opening facing wind.

The maximum value of k will be attained when the Kinetic Energy of the air current is completely converted to Potential Energy.

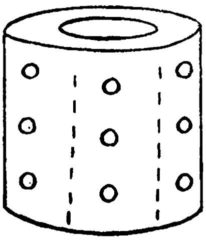
but K.E. $= \frac{1}{2}d\, v^2$ per unit vol.
$\therefore$ in this case $p - p_s = \frac{1}{2}dv^2$

and therefore the maximum value of k is equal to $\frac{1}{2}$. This condition is realised in the case of a cylindrical tube, open at one end, closed at the other, with the open end passing directly into the wind, as in the case of the pressure opening in the Dines anemometer.

Case (2).—k negative—suction or Venturi effect as in the case of the suction tube in the Dines. Here we have a vertical annular tube perforated as in Fig. 1.

Experiments made at the National Physical Laboratory show that the value of k depends partly on the number and size of the holes in relation to the size of the outer tube and the width of the annular space.

Fig 1.



As in this case $p < p_s$, k must have a negative value, and in the Dines is arranged to be equal to $-\frac{1}{4}$.

Case (3).—k zero—Static Tube.

By suitable design, a tube can be constructed such that the increase in pressure as in Case (1) is exactly counter-balanced by the decrease in pressure as in Case (2)—i.e., $k = 0$ and the pressure inside the tube is always equal to the static pressure of the free air no matter what the velocity of the wind may be. Such a tube is known as a Static Tube and has a shape resembling that in Fig. 2.

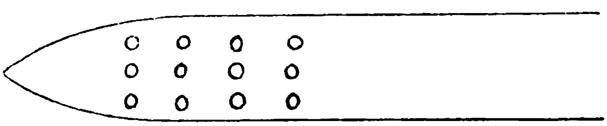


Fig 2

This tube has extensive application for pressure determination on aircraft, etc., where the velocity of the wind is high, and also where accurate determinations of pressure are required.

For the Dines:—

In the suction tube $p - p_s = kdv^2 = -\frac{1}{4}dv^2$.

In the pressure tube $p - p_s = kdv^2 = \frac{1}{2}dv^2$.

Therefore the combined effect produces a difference in pressure of $\frac{3}{4}dv^2$.

$$\text{Now } p \propto v^2$$

$$\therefore v \propto \sqrt{p}.$$

Therefore the scale is not uniform and will close up with increasing velocity. Hence we have to design the instrument so that the movement of the float is proportional to v or $\sqrt{p}$ and then the scale will be linear.

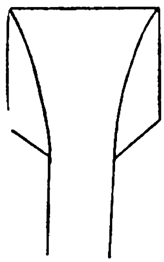


Fig 3a.

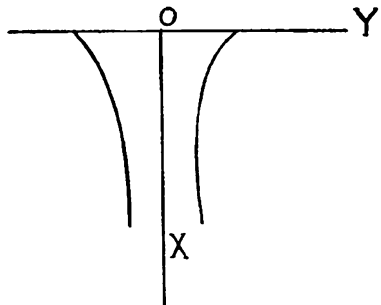


Fig 3b.

This is accomplished by designing the shape of the internal surface of the float as in Fig. 3a, so as to satisfy the relation (as determined by the axes OX, OY in Fig. 3b).

$$y^4 \ (k + h - x) = kc^4$$

where k is a constant,
h is the depth of the water in the tank, which is also constant,
c is the value of y when $x = 0$.

The surface is therefore a quartic hyperboloid of revolution. It can be shown mathematically that a float of this shape will lift a distance proportional to the $\sqrt{p}$., i.e., proportional to v.

It is necessary to satisfy two conditions to arrive at this:—

(1) The level of the water should pass along the y axis (i.e., the top of the curve), when the float is in equilibrium under no force. In this position the bottom of the float is touching the bottom of the tank but not resting on it.

(2) The level of the water in the outer container remains constant if the float is displaced by introducing air into the float. This is strictly true in the case of the float alone, and is almost true in the case of a float into which protrudes the pressure tubing as in the case of the actual instrument.

The Dines instrument uses distilled water as a liquid, as it may be very easily obtained. A disadvantage is that it easily freezes and ruins the float. This may be obviated by using a non-freezing mixture which, however, alters the density of the liquid, and so a new value of h is necessary. Another way of overcoming the difficulty is to use heaters.

The shape of the float of the Dines anemometer is determined by the condition that the distance which it rises above its zero position shall be proportional to the wind speed. Actually this condition cannot be strictly satisfied because the rise of the float

is dependent on the pressure of the wind; and the pressure of the wind depends not only on its speed, but also on the density of the air. The latter in turn depends upon the barometric pressure and the temperature. Accordingly the ideal condition is replaced by the practical one, viz., the rise of the float shall be proportional to the square root of the difference of pressure between the inside and the outside of the float. So long as the temperature and barometric pressure (or the density) do not vary, this will be

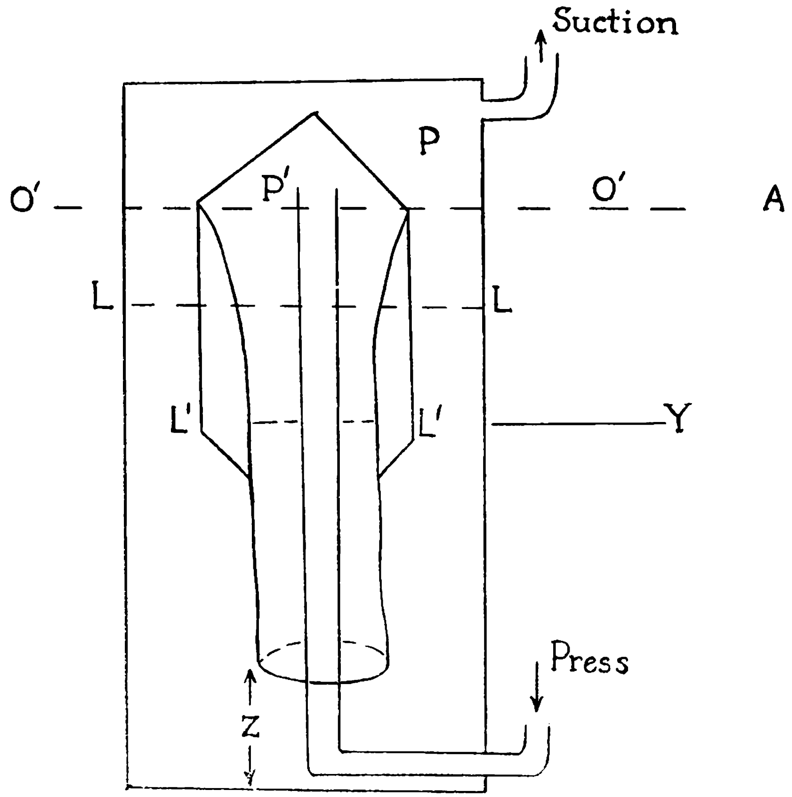


Fig. 4—Diagram of float and container of Dines Anemometer

proportional to the speed. If the instrument is designed to be correct for a mean value of density, then the corrections necessary at the sea level to allow for variations from the mean value may amount in extreme cases to 10%. At a height of 1,000 metres, the average value of the correction will be 5%, i.e., recorded speeds of the wind would be too low by that amount.

Correction for Air Density

In the calibration of the Dines the air density is assumed to be a standard value, i.e., 1250 grams per cubic metre. For any

given pressure difference a variation of the air density from this value will give a false rate of velocity since the difference in pressure $p - p_s = kdv^2$, then for a given pressure difference $p - p_s$ let d_s equal standard density.

d_T = the true density.

v_s = indicated velocity.

v_T = the actual velocity.

Then $p - p_s = kd_sv_s^2 = kd_Tv_T^2$

$$\therefore v_T^2 = v_s^2 \frac{d_s}{d_T}$$

$$\therefore v_T = v_s \sqrt{\frac{d_s}{d_T}}$$

Examples

(1) For air at 770 mm. and at 0° C., the density is 1310 grams per cubic metre.

$$\therefore \frac{v_T}{v_s} = \sqrt{\frac{1250}{1310}} = 0{\cdot}98$$

i.e., the indicated velocity would have to be multiplied by 0·98 to give the true velocity.

(2) For air at 720 mm. and 30° C., the density is 1103 grams per cubic metre.

$$\therefore \frac{v_T}{v_s} = \sqrt{\frac{1250}{1103}} = 1{\cdot}06$$

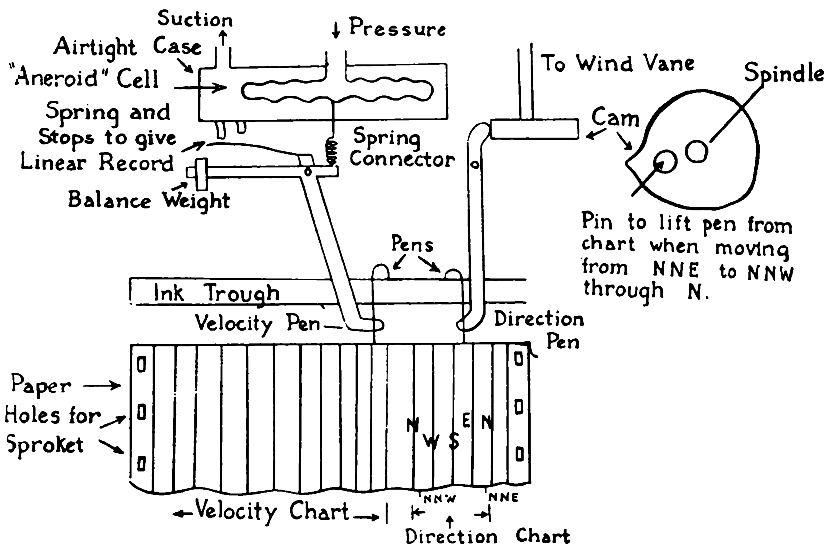
Therefore in this case the indicated velocity would have to be multiplied by 1·06.

2. **Diaphragm Type (Munro)** (G 268/5008)

A new type of recorder is being installed at some aerodromes and this is known as the diaphragm type by reason of the fact that in place of the float it employs a diaphragm membrane, similar to that used in an aneroid barometer, as the pressure recorder. A large diaphragm is used with the interior of the cell connected to the pressure tube and an airtight enclosure around the cell connected to the suction tube. Thus the pressure and suction effects are combined to give a measure of wind velocity which is recorded on a chart by a pen attached to a system of levers. A counter-weight (which tends to return the pen to zero) is fixed to the lever.

It is obvious that the diaphragm type recorder cannot be compensated for the variation in scale value in the same manner as in the float type. However, a spring system is attached to the levers and the variation in the tension on the springs as the velocity increases helps to give a linear scale. The scale is not exactly linear, however, as can be seen from the anemograms.

The direction rod is connected through a universal joint to a cam which has a pen release stop attached to the lower side. As there is only one pen for direction recording, it is necessary for the pen to change from north to north as the direction oscillates about north. The pen is automatically lifted from the paper before transit across the chart. The pens are metal capillary tubes fed from a trough of ink behind the pen arms.



Diaphragm Anemometer

SECTION 12

DISTANT READING AND RECORDING ANEMOMETERS

Most modern types of distant reading and recording anemometers use some form of electrical transmission and some of them will be described briefly.

Distant Recording Cup Anemometer (Velocity only).

The cups drive a small generator situated below the cups. The voltage generated varies with the cup speed. By calibrating the dial of a high resistance voltmeter to read directly in m.p.h. the wind velocity is indicated directly. This device has the advantage that the varying factor for the cup anemometer can be allowed for in the calibration of the dial of the instrument. The advantage of this type is that it is independent of electric sources. It has, however, the disadvantages of the cup anemometer.

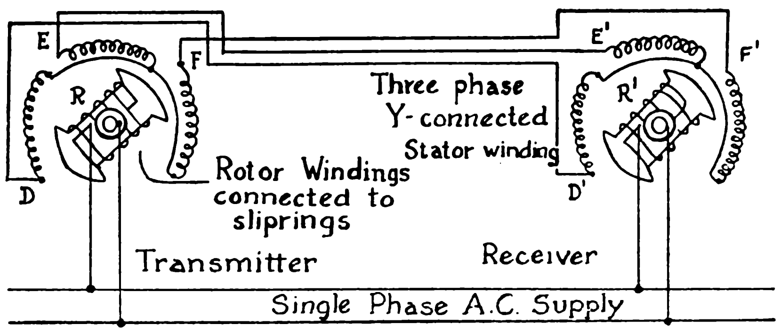
Distance Recording of Wind Direction

One of the simplest ideas consists of an eight-segment commutator contacted by the swinging wind vane. The segments are wired to eight signal lamps arranged round a dial to indicate N., N.E., E., etc. The flashing of the signal lamps indicates the position of the swinging vane. This may be operated either from batteries or by a transformer from an A.C. supply. Another more elaborate system employs self-synchronous units (selsyn units) as indicated below.

Self-Synchronous Units

A "selsyn" or "auto-syn" system consists of two machines—a transmitter and a receiver, which operate in a similar manner to an alternator supplying a synchronous motor. In the case of an alternator direct current excitation is used to provide the magnetic field, with selsyn units alternating current is used for the field excitation. The reason for this is that with a D.C. field no torque can be produced at standstill since the field is not moving with respect to the armature. With A.C. excitation mechanical motion is not necessary to produce torque and the receiver and trans-

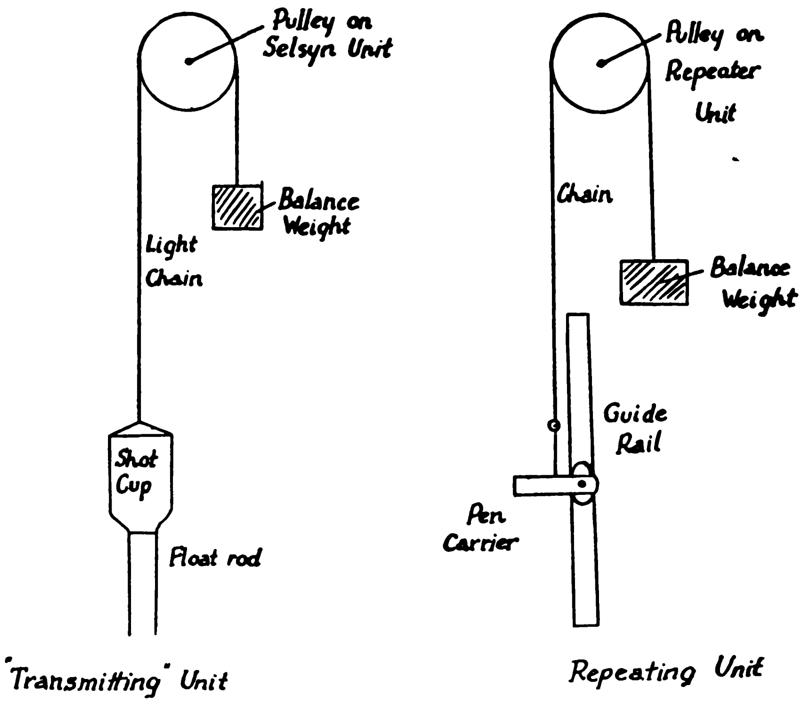
mitter can lock together at all speeds including standstill. In the diagram below, R and R^1 are the rotors of the transmitter and receiver, D, E, F, and D^1, E^1, F^1 are the stator coils. The rotors R and R^1 are wired in parallel and A.C. supplied. While R and R^1 occupy the same position relative to their stators the e.m.fs. induced in the stator coils are equal and in the same phase, and so can be inter-wired so that the induced e.m.fs. neutralise each other. If, however, there is an angular displacement between the rotors R and R^1 this balance is upset and induced currents flow in the stator coils and produce torques tending to restore R and R^1 to coincident positions. Hence, if the rotor of one unit is forcibly turned the rotor of the other will follow it. These units can only be used where an A.C. supply is available.



Self-Synchronous Units Applied to Anemometers

For the distant recording of wind direction one "auto-syn" unit is attached just below the wind vane so that the swinging of the vane rotates the rotor of the unit. The rotor of the receiving unit situated at the distant station will follow that of the transmitter and so operates the indicator and recorder.

A pair of smaller self-synchronous units may be used for transmission of wind velocity from a float type anemometer. The translational motion of the float is converted into rotational motion at the rotor of the transmitting unit by using a pulley and chain. The chain connected to the float passes over a pulley and has a counter-balance weight at the other end. As the float rises and falls the pulley wheel, which is connected to the rotor of the transmitter, turns backwards and forwards. The rotor of the receiving unit at the other end repeats the motion.



Auto Selsyn Units applied to Float Type Anemometer

SECTION 13

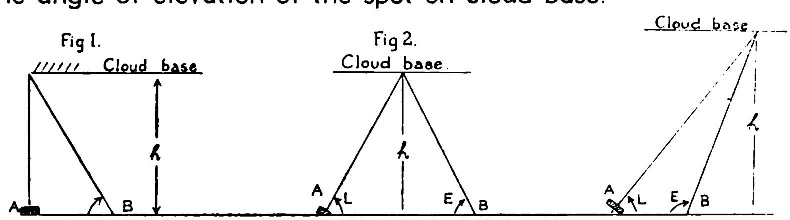
THE CLOUD SEARCHLIGHT

PRINCIPLE

A beam of light is projected upwards at a known angle at one end of a fixed base line (this base line and the projected beam must be in the same vertical plane) and at the other end the vertical angle between the horizontal and the spot of light projected on to cloud is measured. The cloud height is then simply obtained in terms of the length of base, angle of projection of beam and the vertical angle of the spot of light.

THEORY

Two types are in use, one, portable (Vocab. No. G 268/5146), with a vertical beam, and the other a fixed type (G 268/5145), with an inclined beam. With the latter type two cases may arise, the angle of elevation of the spot on the cloud may be acute or obtuse, depending on the height of the cloud. The situations are illustrated in Figs. 1, 2, 3, where AB is the base line and E the angle of elevation of the spot on cloud base.



If we represent height of cloud base by "h" and the angle of elevation of the beam by L we get for the three figures

Fig. 1 $h = AB \tan E$ Fig. 2 $h = \dfrac{\tan E + \tan L}{b \tan L \tan E}$

Fig. 3 $h = \dfrac{b \tan L \tan E}{\tan E - \tan L}$

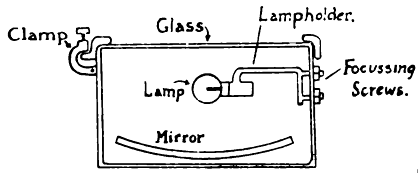
As a result of experimental work it has been found that for average cloud heights the inclined beam is most accurate, but has the disadvantage of difficulty of original setting up. The angle used is 63° 26′, the tangent of which is 2 and so the relation becomes for Fig. 2 $h = \dfrac{2\, b \tan E}{2 + \tan E}$ and for Fig. 3 $h = \dfrac{2\, b \tan E}{\tan E - 2}$

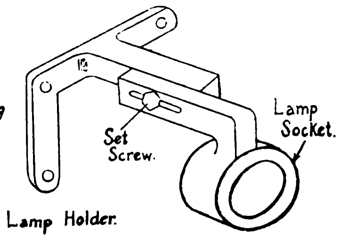
SEARCHLIGHT

(1) Description

The searchlight consists of a high power light globe mounted In a case with a 16-inch diameter glass parabolic mirror to reflect the light. The whole system is designed to throw out a parallel beam of light.

The portable type is levelled by means of three adjustable feet in conjunction with two bubble levels mounted at right angles to one another on the side of the case, then at night the bulb is adjusted so that, when viewed from several places some distance away, the beam appears parallel and vertical.





2. **Focusing**

Place the bulb in the socket and adjust the position of the socket on slide so that the filament is approximately centred over the reflector, then tighten the set screw. The main external focussing screws are situated on the outside of the metal case of the light. Care must be taken, after carefully focussing, to tighten the lock nuts on these screws. It will be found that the light may be focused most easily on a dark night with middle level cloud by means of these three screws.

Adjust the top two main focussing screws until the lamp is in the exact centre, laterally, of the glass mirror. (This can be measured with the aid of a rule.) It will be seen that the third focussing screw will move the lamp assembly to any desired distance from this glass mirror. The first adjustment, that is the lateral adjustment, should be executed in daylight, and the second adjustment, that is distance from mirror, should be done in the dark with the lamp working, to obtain a parallel beam.

3. **Setting Angle**

(a) Portable Type.—Level by means of adjustable feet and levels on side of case.

(b) Fixed Type.—First set the beam to approximately 63° as indicated on the searchlight mounting itself, and with the theodolite correctly set up at point B (observing point) check the beam to make sure it passes vertically overhead at B. If not, rotate searchlight on its mounting until this condition is satisfied; next set the theodolite up as close to the searchlight as possible, and sight the theodolite on to the spot of light projected on cloud, preferably middle level cloud (6000-15,000 feet). The angle of elevation indicated by the theodolite should be 63° 26″. If not, elevate searchlight beam until this condition is satisfied. The searchlight is now completely set up for cloud observation.

4. **General**

The searchlight will be wired with a switch located in the Meteorological Office, situated as closely to B as local conditions allow, that is, when this base line AB is being surveyed every effort should be made to arrange that end B of the base line will be as close as possible to the Meteorological Office.

The length of the base line depends on local conditions but is usually 500 feet; more accurate observations are obtained by a base line of 1000 feet.

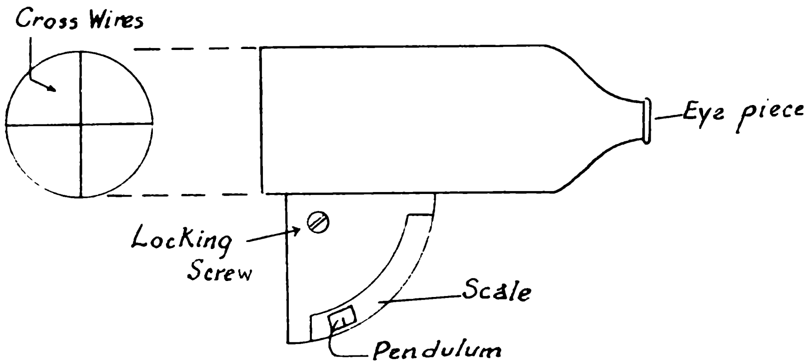
The lamp requires 12 volts at 35 amps and has a useful life of only 100 hours, and therefore should not be left in operation for a length of time greater than that required to take a reading. A transformer is supplied with the unit to use standard power supply for operation of the lamp.

Weekly cleaning routine should be adopted with regard to the mirror and the outside cover glass. Any non-abrasive cloth will be quite satisfactory.

Clinometer (G 268/5089)

This consists of an aluminium "bottle" with cross wires in the larger end and a small hole in the "eye" end. It has a quadrant attached to it and a pointer, actually a pendulum, which may be locked by a knurled knob.

To take a reading, hold the clinometer in the right hand and sight so that the cross wires intersect the centre of the spot of light on the cloud; when this condition is satisfied, lock the gravity control pointer by tightening the screw on the left-hand side of the instrument. It is advisable to take at least three readings and mean the height obtained. The clinometer will read accurately only if the quadrant is in a vertical plane. The clinometer with practice should give readings to an accuracy of plus or minus 1°. Tables giving the cloud height directly from elevation angles for both Case (1) and Case (2) will be supplied with each searchlight.



SECTION 14

AIRCRAFT INSTRUMENTS

1. Altimeters.

The altimeter is an adaptation of the aneroid barometer to indicate altitude instead of pressure and is graduated for an altitude scale that is purely arbitrary. Actually the rate of decrease of pressure with height depends upon the vertical distribution of temperature and humidity.

Two methods of calibration of altimeters are in use:—

(i) **The Isothermal Law**

$H = 221T \log \frac{Po}{P}$ where T = The uniform temperature of air column of height H ft.

Po = Sea Level pressure.

P = Pressure at Height H ft.

For calibrating according to this law an arbitrary atmosphere is assumed in which the effect of water vapour is neglected and the temperature of the atmosphere assumed to be a uniform temperature of 10° C = 50° F. throughout and sea level pressure to be 29·92 inches. If the air temperature is above or below 50° F. the plane would be above or below the indicated height. The correction for this is easily obtained from the following rule:—

For every degree Fahrenheit increase or decrease of the mean temperature of the air column above 50° F. add or subtract 1/500 of the observed height to give the true height,

e.g., Temperature at ground = 77·0° F.

" " 1,000 = 74·3° F.

" " 2,000 = 71·6° F.

" " 3,000 = 68·9° F.

" " 4,000 = 64·4° F.

Mean temperature of air column = 71·2° F.

$\therefore$ Correction $= \frac{1}{500} \times 4000 \times 21{\cdot}2 = 169{\cdot}6$.

Hence corrected altitude = 4170 feet approximately.

(ii) **The I.C.A.N. Law**

The calibration according to this law assumes an abitrary atmosphere in which the effect of water vapour is neglected, the ground temperature assumed to be 15° C., and a uniform lapse rate of 1·98° C./1000 feet, assumed to 36,090 feet. Above that height the air temperature is assumed constant and equal to —56·5° C. The sea level pressure is taken to be 29·92 inches.

The I.C.A.N. Law represents the decrease of pressure with altitude under average conditions more accurately than does the Isothermal Law, though the Isothermal allows of more simple correction.

Correction for I.C.A.N. altimeters—

$$H_T = H_I \times \frac{T_{ma}}{T_{ms}}$$

where H_T = True height.

H_I = Indicated height.

T_{ma} = Mean temperature of air column on absolute temperature scale.

T_{ms} = Mean temperature of air column on I.C.A.N. standard atmosphere between H = O and H = H_I in absolute units.

Pressure corresponding to various indicated heights on each system:—

Height feet	Isothermal Pressure in inches.	I.C.A.N. Pressure in inches.
0	29·92	29·92
1,000	28·84	28·86
3,000	26·79	26·82
5,000	24·89	24·90
10,000	20·71	20·58
20,000	14·54	13·75
30,000	9·92	8·89

Pressure Altitude is the altitude on the table of I.C.A.N. values which corresponds to a particular barometric pressure, that is, if the actual barometric pressure is 20·58 inches, then the altitude given on the I.C.A.N. table of standard atmospheric values is the "pressure altitude" (10,000 feet), but the actual altitude may be something quite different.

Four Limitations of an Aneroid as an Altimeter

1. It is calibrated for average atmospheric conditions and is, therefore, subject to errors under any other conditions.

2. If set for zero at sea level before a flight, it will give reasonably accurate readings during flight only provided that no change in atmospheric pressure takes place during the flight. This is usually not so since it is most unlikely—

(a) That the general pressure distribution is unchanging;

(b) that the flight of the aircraft does not take it over regions of varying pressure.

3. It is subject to "cockpit error." To avoid this, the case of the aneroid is usually sealed and connected to a "static tube." (See Section 11.)

4. During ascent and descent it is subject to lag errors.

The error (2) is most important.

E.g., suppose the sea level pressure at Brisbane is 30·0 inches and a pilot leaving Brisbane sets his altimeter to zero for sea-level pressure. Now suppose the sea-level pressure at Melbourne is only 29·5 inches. This means that when the plane is at sea level at Melbourne the altimeter will be subjected to 29·5 inches pressure. But the altimeter was originally set for a sea-level pressure of 30·0 inches and, therefore, under a pressure of 29·5 inches it will read about 500 feet. Hence, if not allowed for, such a change of pressure could cause a serious accident since, if the ground were obscured by low cloud, the pilot would think that he had 500 feet more altitude than he actually had.

Sensitive Landing Altimeter

Recently great improvements have been made in altimeter design resulting in the production of much greater sensitivity combined with the big range now required. The Kollsman sensitive altimeter is one of the best known types. The instrument has two hands similar to those of a clock. The long hand reads hundreds of feet on the scale, each small scale division representing 20 feet and one complete revolution round the dial representing 1000 feet. The small hand reads thousands of feet, one complete revolution representing 10,000 feet. A small knob on the case of the instrument enables the hands to be set at any desired reading. When the altimeter is being set the cage containing the aneroid cell is rotated; this rotates the hands and mechanism and is exactly the same as moving the dial. The setting knob is also geared to a second dial, visible through a window in the altitude dial, which indicates the pressure on the I.C.A.N. scale that would make the instrument indicate zero altitude. This pressure, shown in millibars, is known as a Kollsman number. The pressure scale is graduated for two-millibar intervals.

Kollsman Numbers

If the aerodrome office is equipped with a sensitive altimeter of the same type as those used in the aircraft, two forms of Kollsman numbers can be supplied in reply to coded requests—

(1) Station Level Kollsman Number;

(2) Sea Level Kollsman Number;

which can be obtained in the following manner:—

1. The knob of the airport ailtimeter is turned till the hands on the altitude dial read zero. The number which then shows on the barometric dial is transmitted to the aircraft. The pilot sets this same reading on the barometric dial of the plane's altimeter, the altitude scale of which then shows the height of the plane above **aerodrome** level and will indicate zero on landing.

2. The knob of the airport altimeter is turned till the hands on the altitude dial read the **height** of the aerodrome **above sea level.** The number then showing on the barometric dial is then radioed to the plane as before. The pilot sets the number on the barometric dial of the plane's altimeter, the altitude dial of which then shows the height of the aircraft above **sea level.** The sea-level Kollsman number will be different from the sea-level barometer reading because the standard atmosphere assumed for the calibration of the altimeter will, in general, not be that assumed for the reduction of the barometer reading. The difference between the two sea-level pressures may be equivalent to as much as 40 feet in 500 feet.

(3) To obtain sea level Kollsman number from station mercury barometer—

Read barometer and correct to station level pressure; this is identical with station level Kollsman number. The correction to sea level for synoptic purposes assumed that the temperature of the fictitious air column is uniformly the same as the temperature of the air at the station.

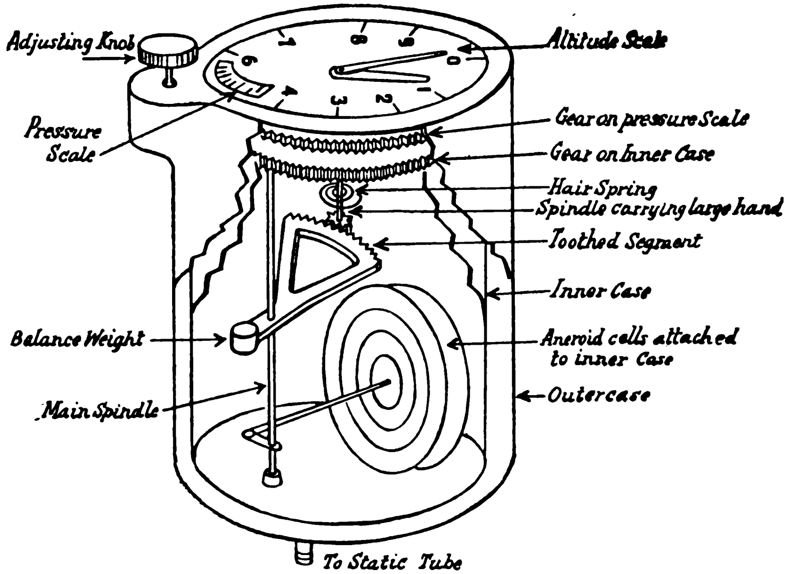
For I.C.A.N. conditions, a standard surface temperature of 59° F. and a lapse rate of 1·98° C. is assumed.

And thus the mean sea level pressure is, in general, not equivalent to the sea level Kollsman number, but the latter is actually the pressure on the standard atmosphere scale which corresponds to an altitude equal to the difference between the true altitude and the pressure altitude. For example, if the station level pressure is 859 mb. and the altitude of station is 4227 feet—

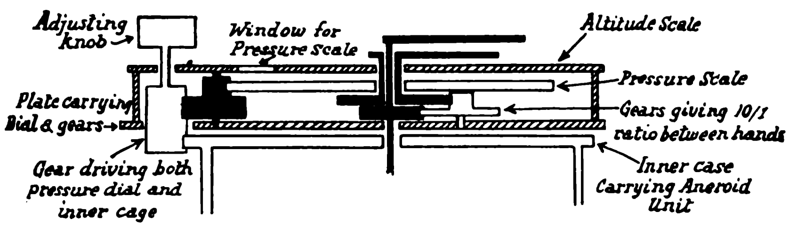
(1) Look up altitude on I.C.A.N. pressure altitude scale corresponding to 859 mb., i.e., 4488 feet.

(2) Subtract station level from this height—
4488 — 4227 = 261 feet.

(3) Look up pressure on I.C.A.N. scale for 261 feet. This is 1004mb. which is M.S.L. Kollsman number to the nearest whole millibar.



Cut away of Sensitive Altimeter



Section through top of Sensitive Altimeter
Showing gearing for pressure dial and hands.

ALTIMETER SCALES

Survey Altimeter

The survey altimeter has a linear pressure scale and, as the relation between pressure and height is logarithmic (*see* Physical Notes) the height scale closes up with decreasing pressure.

If pressure at height $z_1 = p_1$ and at $z_2 = p_2$

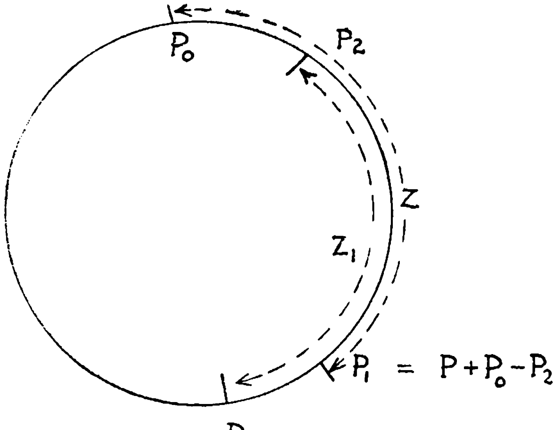
$$\text{then } z_2 - z_1 = \frac{RT}{g} \log \frac{p_2}{p_1}$$

for an isothermal atmosphere.

If p_1 is mean sea level pressure, then $z_1 = o$ and the correct height will be indicated if the mean sea level pressure is 29·92 inches (neglecting temperature effects).

In general the mean sea level pressure will not be at 29·92 inches, and to correct for this we have to make the height scale movable to allow the zero to be set against the indicated sea level pressure. This procedure introduces errors at other heights.

Suppose the height scale is adjusted to show zero at a pressure of p_2, then the height interval from p_2 to p will be the same as the height interval from p_o to p minus the height interval from p_o to p_2 on the unadjusted scale.



$$\text{The true height } z = \frac{RT}{g} \log \frac{P_2}{P}$$

$$\text{The apparent height } z_1 = \frac{RT}{g} \log \frac{P_o}{P + P_o - P_2}$$

$$\text{Therefore the error } z_1 - z = \frac{RT}{g} \log \left(\frac{P_o}{p - p_2 + p_o} - \log \frac{p_2}{p} \right)$$

This error amounts to over 1,000 feet at 15,000 feet, if the ground pressure departs 1½ inches from the normal 29·92 inches.

Aircraft Altimeter (Isothermal atmosphere)

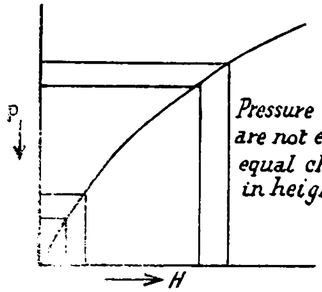
Where the aneroid barometer is to be used solely as an altimeter as in aircraft, it is calibrated solely in height units and not in uniform pressure divisions, and this eliminates the error as discussed in the survey type.

From the equation—

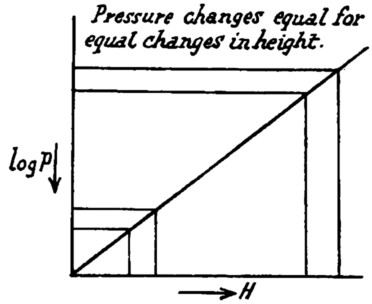
$$z_2 - z_1 = \frac{RT}{g} \log_e \frac{p_2}{p_1}$$

it is apparent that if $z_2 - z_1$ is a constant interval then $\frac{p_2}{p_1}$ will also be constant, and for 1,000 feet intervals has the value of 0·964 (if g is taken as 980·6).

i.e., $p_2 = p_1 \times (0{\cdot}964)^n$ where n = altitude in thousands of feet.



Pressure-height isothermal at 283° A.



Log pressure-height isothermal at 283° A.

These two isothermals indicate how the altimeter, graduated on a pressure height isothermal, has errors when the zero is moved from 29·92 inches, whereas the one graduated on the log pressure height isothermal has no error when the zero is moved from 29·92 inches. In practice, instead of altering the scale of such an altimeter the whole aneroid unit is moved to keep the zero of the scale in the topmost position of the dial.

An example to illustrate the principle is:—

If sea level pressure is 29·92 inches, and the isothermal atmosphere at 283° A,

the pressure at 10,000 ft. $= 29{\cdot}92 \times (0{\cdot}964)^{10} = 20{\cdot}71$ in.

If sea level pressure changes to 30·92 inches while the temperature remains the same, the pressure at 10,000 feet has become $30{\cdot}92 \times (0{\cdot}964)^{10} = 21{\cdot}40$ inches. The linear distance moved by zero of the scale is log. 30·92 — log. 29·92 = 0·0143 units. The linear distance that the 10,000-ft. mark is moved will be the same, and this is also the difference between the logs of 21·40 and 20·71, so no correction is required for such an altimeter.

Table Showing I.C.A.N. Atmosphere Relations

Altitude Feet	Pressure Inches	Pressure Mb.	Air Temp. C.	Altitude Feet	Pressure Inches	Pressure Mb.	Air Temp. C.
—200	30·14	1020·6	15·5°	1,000	28·86	977·3	13°
—180	30·12	1020·0	15·5°	1,500	28·33	959·3	12°
—120	30·10	1019·3	15·5°	2,000	27·82	942·1	11°
—160	30·07	1018·3	15·5°	2,500	27·31	924·8	10°
—140	30·05	1017·6	15°	3,000	26·81	908·0	9°
—100	30·03	1016·9	15°	3,500	26·32	891·4	8°
—80	30·01	1016·2	15°	4,000	25·84	875·1	7°
—60	29·99	1015·6	15°	4,500	25·36	858·8	6°
—40	29·96	1014·5	15°	5,000	24·89	843·0	5°
—20	29·94	1013·9	15°	6,000	23·98	812·4	3°
0	29·92	1013·2	15°	7,000	23·09	782·0	1°
50	29·87	1011·5	15°	8,000	22·22	742·5	—1°
100	29·81	1009·5	15°	9,000	21·38	724·1	—3°
150	29·76	1007·8	14·5°	10,000	20·58	697·0	—5°
200	29·71	1006·1	14·5°	11,000	19·79	670·2	—7°
250	29·65	1004·0	14·5°	12,000	19·03	644·4	—9°
300	29·60	1002·4	14°	13,000	18·29	619·3	—11°
400	29·49	998·6	14°	14,000	17·57	595·0	—13°
500	29·38	994·9	14°	15,000	16·88	571·6	—15°
600	29·28	991·5	13·5°	16,000	16·21	548·9	—17°
700	29·17	987·8	13·5°	17,000	15·56	526·9	—18°
800	29·07	984·4	13·5°	18,000	14·94	509·3	—21°
900	28·96	980·7	13°	20,000	13·75	465·6	—25°

Air-Speed Indicators

The air-speed indicator is used to indicate the speed of the aircraft relative to the air. This air-speed must be distinguished from the ground-speed which is the resultant obtained by combining the air-speed with the wind-speed.

There are two types, one an aneroid type, the other on the lines of the plate anemometer, but this type is only used on training planes. The aneroid air-speed indicator consists of two main parts—

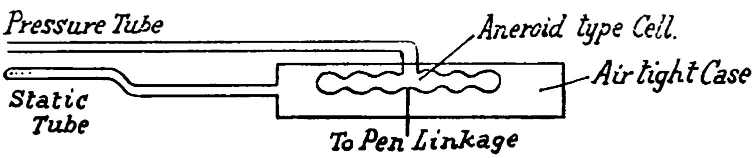
(i) The pressure head or pitot tube;
(ii) The pressure gauge.

The Pressure Head and Pitot Tube

This comprises the pressure and static tubes mounted on a part of the aircraft free from the effects of slip-stream, eddying, etc. The pressure tube is open at the forward end and faces directly into the air-stream. The resulting pressure is conveyed through a connecting tube to the pressure side of the pressure gauge mounted in the pilot's cockpit. The static tube is closed

and cone shaped at its forward end, but is pierced by a series of small holes along its sides. The pressure in the static tube is very nearly the same as the pressure of the surrounding air independent of the rate at which the static tube is moving through the air. The static tube is connected by tubing to the static side of the pressure gauge which is thus operated by the difference of pressure between the pressure tube and the static tube.

The pressure gauge consists of an elastic metal box with thin corrugated sides. One side of the box is connected to the case of the instrument while the other is connected through a suitable magnifying lever system to a pointer moving over a scale. The pressure tube connects to the interior of the diaphragm box while the static tube connects to the airtight case.



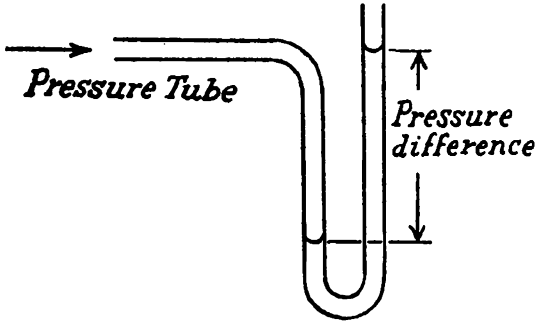
Hence increases in the speed of the plane transmits increased pressure to the inside of the diaphragm box, the resulting expansion of which is indicated by movement of the pointer over a scale. The scale is usually marked in m.p.h. on British and American instruments. Older types of air-speed indicator used a diaphragm of oiled silk, which, while very sensitive, suffers rapid deterioration especially in hot climates. Modern types use diaphragm boxes made of carefully annealed and aged nickel-silver.

It can be shown theoretically that the pressure in the pressure tube is proportional to the square of the velocity and also to the density of the air.

$$p \propto d\,v^2$$

To give an idea of the pressure induced by a pitot tube on an aircraft, the following table is included, the pressure difference being in mms. of water.

Air Speed	Pressure Difference	Air Speed	Pressure Difference
40	20·0	140	247·1
50	31·3	150	284·0
60	45·1	160	323·6
70	61·4	170	365·8
80	80·2	180	410·7
90	101·6	190	458·3
100	125·6	200	508·7
110	152·1	210	561·8
120	181·2	220	617·6
130	212·8	230	676·3



Since the density of the air decreases with height then the air-speed indicator will give lower readings at high than at low altitudes. Thus, if at 10,000 feet the indicated speed is 100 m.p.h. and at 1,000 feet the indicated speed is 100 m.p.h., the true air-speed at the higher level will be greater than 100 m.p.h.

The instrument is calibrated assuming an arbitrary standard atmosphere and corrections can be applied by means of specially devised mechanical calculators. An approximate corrections is to add 2% per thousand feet above sea level, i.e., if

h = altitude in 1,000's of feet,

s = indicated air-speed in m.p.h.

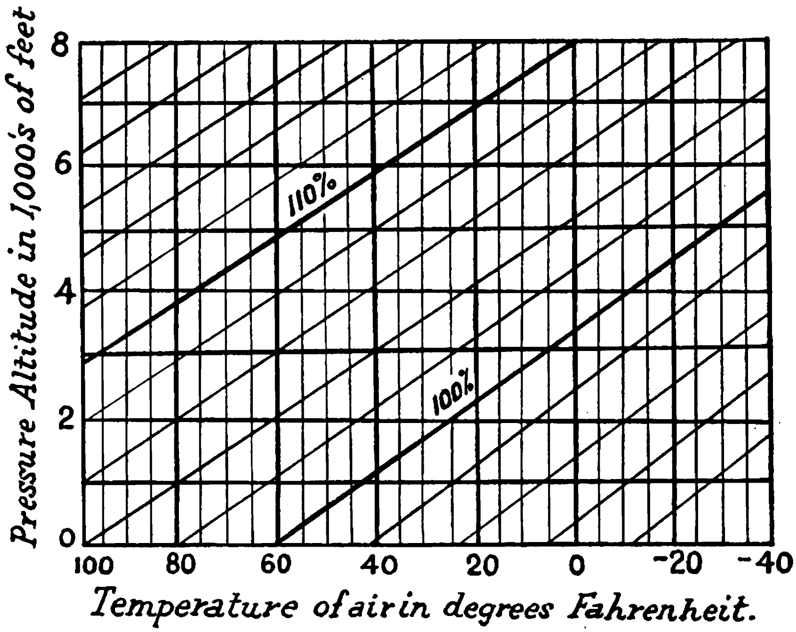
Correction $= \dfrac{h \times s}{50}$ m.p.h. to be added on to indicated air-speed,

that is, at 10,000 feet with an indicated speed of 100 m.p.h. the true speed would be approximately 120 m.p.h.

Knowing the indicated air-speed, pressure, altitude and temperature, a graph can be constructed giving the percentage that the true air-speed is of the indicated air-speed. To use the graph proceed as follows:—Find the horizontal line corresponding to altitude (say, 6,500 feet), move along this line until the vertical line representing air temperature is reached (50° F.). The sloping line through this point (112%) gives the percentage that the true speed is of the indicated air-speed.

Each sloping line indicates 2%.

A second graph is used to obtain the actual air-speed.



Graph to find Percentage of Air Speed

3. **Aircraft Thermometers**

Various types of thermometers find a use on modern aircraft and the following are used for particular purposes.

(i) **The Mercury in Steel Thermometer:** Described in Section 1.

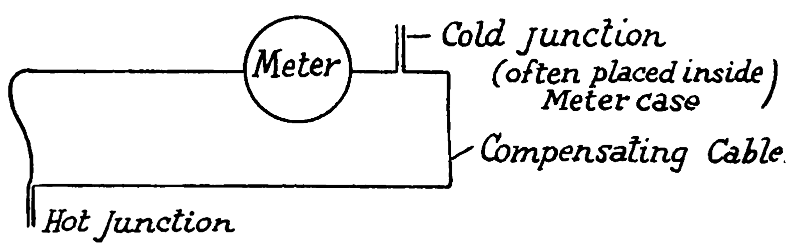
(ii) **Liquid Radiator Thermometer:** For giving radiator temperatures in liquid-cooled engines a type of thermometer somewhat similar to the above type, but containing ether, is used. The bulb is of brass or copper. The capillary tube is of copper (1 mm. bore). The indicator is a Bourdon type pressure gauge. The capillary tube projects down from the top of the bulb reaching almost to the bottom. The capillary and part of the bulb are filled with ether, the remainder of the bulb with ether vapour. Hence the pressure inside the bulb is the vapour pressure of the ether of the particular temperature and is quite independent of the volume of the bulb. Variations in temperature thus cause variations in vapour pressure which are registered by the Bourdon gauge. With this ther-

mometer since the internal pressures in the system are comparatively small the changes in the external pressure, acting in the Bourdon gauge, due to changes in altitude, are quite considerable. At high altitudes the thermometer will obviously read too high. An instrument reading 80° C. at ground level would read 85° C. for the same temperature at 20,000 feet.

(iii) **Electrical Resistance Thermometers** as described in Section 15 are also used to measure oil and air temperatures. Often a single dial with a switching panel is used to indicate, separately, temperatures of different resistance units.

4. **Thermocouples**

Temperatures of various parts of aero engines are now being indicated by means of thermocouples. These are merely a junction of two dissimilar metals and when the junction is heated a potential is set up across the junction. The potential produced is indicated on a millivolt meter and then is graduated to indicate temperatures. Actually a thermocouple must have two junctions—one "hot" and one "cold," as the "cold" one is usually at air temperature and this is variable. A zero corrector is provided on the indicator to allow the zero to be set. A thermocouple is very light, compact and requires no external energy for operation.



SECTION 15

ELECTRICAL RESISTANCE THERMOMETERS

Electrical resistance thermometers work on the change of resistance of metals with a change in temperature. The change of resistance causes a change in current flow. The resistance element is wired into a wheatstone bridge network and then any change of temperature, i.e., of resistance, is shown by the milli-ampmeter which is graduated to show temperatures.

The basic circuit being:—

P and Q equal resistances.

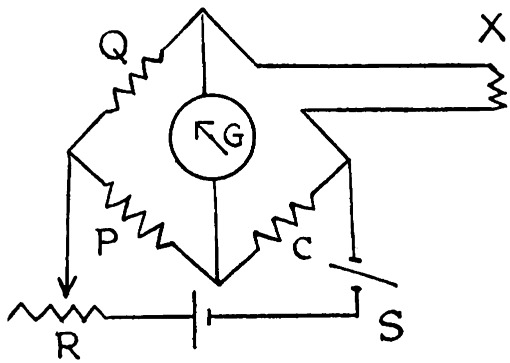
G—Galvanometer.

R—Battery compensating resistance.

S—Switch.

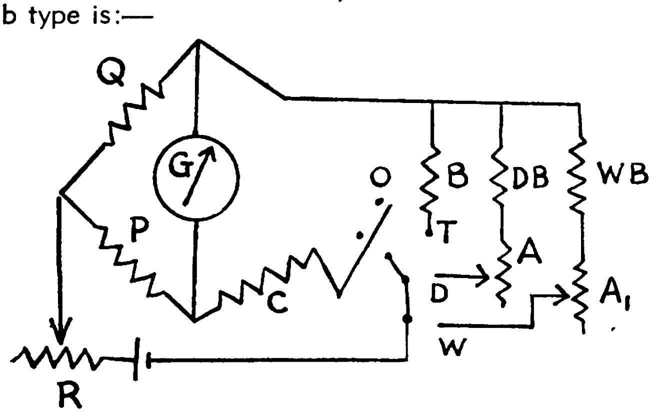
C—Compensating resistance for X.

X—Temperature resistance element.



In the type used in meteorological offices (G 268/5166) P and Q are of 100 ohms and C 80 ohms. The resistance element X is a commercial production. The rheostat R is used to compensate for variations in the battery voltage (4½) with age.

Several modifications have been incorporated in the instrument which increases its accuracy. The circuit for the wet and dry bulb type is:—



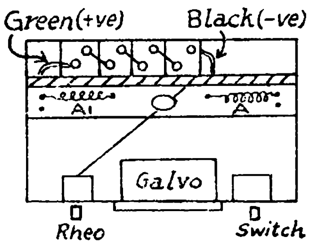
B is a standard resistance of 115 ohms.

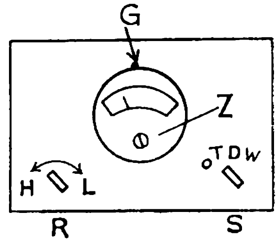
DB WB, temperature elements.

A A_1, variable 7-ohm resistances to compensate for length of connections.

T = Test D = Dry bulb W = Wet bulb O = Off	Switch Positions

The resistance of the leads should not exceed 6 ohms (including resistance A). The complete equipment is mounted in a box which has a compartment for the batteries and the variable resistance R and selector switch mounted on the front panel, below and to each side of the galvanometer which is graduated to read Fahrenheit temperatures from 20° to 120°. On removing six screws from the top of the box the lid will lift off and the terminals and connection compensating resistances can be seen. The "dry bulb" connections being on the right-hand side.





To instal—

(1) Fix resistance elements brackets in screen, screw elements into the brackets.

(2) Connect elements to appropriate terminals in the box.

(3) Adjust zero of meter by screw Z on front of it until pointer reads 20.

(4) Switch to T and adjust R until 120 is indicated, switch off.

(5) Replace element to be the "dry bulb" by the standard coil supplied.

(6) Switch to D and adjust resistance A in box until the temperature shown on standard coil is indicated, switch off.

(7) Replace element.

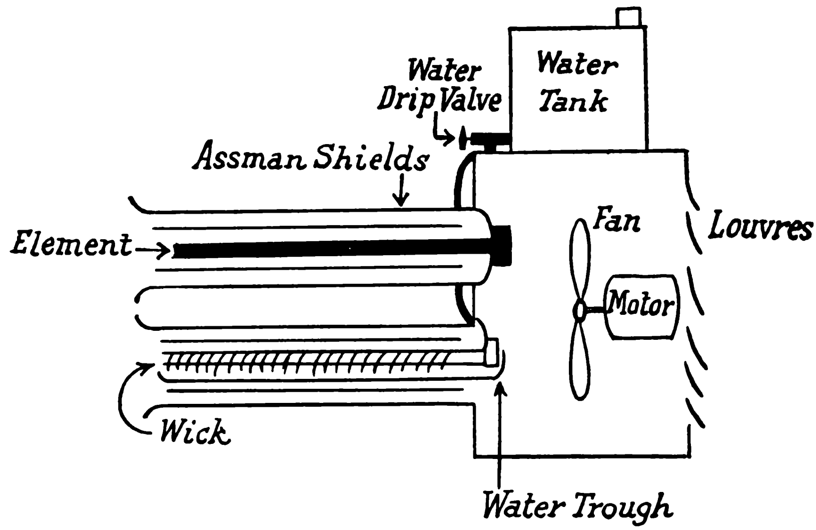
(8) Repeat for the wet bulb element.

The projecting pieces of resistance A or A_1 should not be cut off but coiled up in the event of the connecting wires being altered at any time or the position of the instrument altered. The standard coil is made of "Eureka manganin" wire which is not affected by temperature. When the instrument is set up this coil **must** be returned to the Central Office.

When the resistance will not allow for correct test adjustment the batteries should be renewed. The green wire is connected to the positive terminal.

The resistance elements supplied are wound with platinum wire and for temperatures up to 100° C. it is silk covered, varnish covered and baked. The whole is mounted in a metal thimble.

Best results are obtained if the elements are aspirated and an aspirated type has been produced using Assman type shields.



Aspirated Type

Electrolytic Resistors

Electrolytic resistors of many types and kinds have been made in the past, but most of them were subject to limitations of polarization, gassing, or lack of permanence. The use of electrolytic resistors has been confined, therefore, to applications in which these detrimental features were not objectionable or for which they possessed some positive advantages. Because of polarization and gassing when used with direct current, electrolytic resistors are more generally associated with alternating current circuits. However, certain types may be used successfully in direct current circuits; a type developed primarily for temperature indicators on radio meteorographs where variable direct currents are used is described below.

Electrolytic resistors for this purpose require (1) a large temperature coefficient, (2) a freezing point below any probable atmospheric temperature, (3) light weight (4) reversibility of electrochemical reactions, (5) stability of calibration; (6) hermetical sealing (7) high resistance with a minimum of inductance and capacitance, and (8) rapid response to temperature changes.

Although a number of electrolytes might be chosen which would fulfil satisfactorily the requirements of resistance and large temperature coefficient, the other requirements limit the choice of materials. Certain copper solutions, described below, to which ethyl alcohol has been added in sufficient quantities to depress the freezing point, have been found to be well adapted to the purpose. The alcohol affords a convenient means of adjusting

the resistivity of the solution to the most advantageous value for any particular problem.

The use of electrolytic resistors is by no means limited to radio meteorographs. Because of their stability and high-temperature coefficents they may find application to the control of temperatures when the current passing through the cell is very small.

Because of their high resistance with low capacitance and inductance they should find other applications where such characteristics are desirable.

Early designs of electrolytic resistors employing platinum electrodes in sulphuric acid solutions proved to be somewhat unsatisfactory because of polarization and the evolution of gas, the latter requiring that the resistors be provided with expansion chambers or vents. Gassing was naturally reduced when copper electrodes were used in copper sulphate solutions, but the limited solubility of copper sulphate in sulphuric acid, particularly at the low temperatures, limited the development of such resistors. Improved performance and simplification were provided, however, by the use of hydrochloric acid, ethyl alcohol, and cuprous chloride.

The solutions used in the resistors contained varying amounts of hydrochloric acid (36%; sp. gr. 1·18), ethyl alcohol (95%) and cuprous chloride. The actual solution used depends upon the range to be covered and the permissible resistance range.

They, however, contained some cupric salt, part of which is initially present in the cuprous chloride and part formed by unavoidable exposure of the solutions to the air either while being prepared or used. There is, therefore, some uncertainty in the concentration of copper in these solutions. The presence of the cupric ion in the solutions necessitates calibration of the resistors after reduction of the cupric ion by the copper electrodes. When reduction is completed the solutions become colourless.

Capillary U tubes of approximately 1 mm. bore serve to hold the solution and electrodes. The length of the capillary joining the bulbs blown on each end depends upon the resistance intended for each tube. The electrodes used in the resistors are pieces of size 18 AWG annealed copper wire. The tubes are filled to the upper ends of the bulbs with a small pipette drawn out to a fine capillary. The electrodes are inserted into the capillaries of the U tube and terminate in the bulbs. They are held in place and the tubes sealed with De Khotinsky cement. This method of sealing the resistors proves to be satisfactory for the work if a sufficient length of capillary is provided above the bulbs to permit satisfactory sealing. By means of a bridge and a suitable galvanometer, the resistance of the tube can be found at various temperatures and then interpolation will give intermediate values.

SECTION 16

Radiosondes

A radiosonde is a meteorological unit used to give information regarding the atmosphere. It consists of two essential parts —a meteorological section and a radio transmitter.

The radio transmitter is as small and simple as possible to carry out the required functions. It consists of two sections, one giving a fixed frequency carrier wave, the other a variable modulation wave controlled by the meteorological instruments.

The whole radiosonde, which is actually a meteorograph, is lifted through the atmosphere by one or more balloons. It is fitted with a parachute to restrict rate of descent after the bursting of the balloon.

The rate of ascent to be used is determined by the speed of response of the various elements used. The faster the rate the more nearly will the sounding approach to a vertical one; also a shorter time will be required to obtain the information.

The meteorological section comprises three elements giving pressure, temperature and humidity. As it has to be carried by a balloon the weight must be kept low. The instrument must be robust and yet sensitive since it is expected to work over a pressure range of 1050 to 25 mb., temperature range from $+ 40°$ C. to $- 90°$ C., and humidity from 5% to 100%.

Satisfactory units have been manufactured with a total weight of approximately 2 lbs.

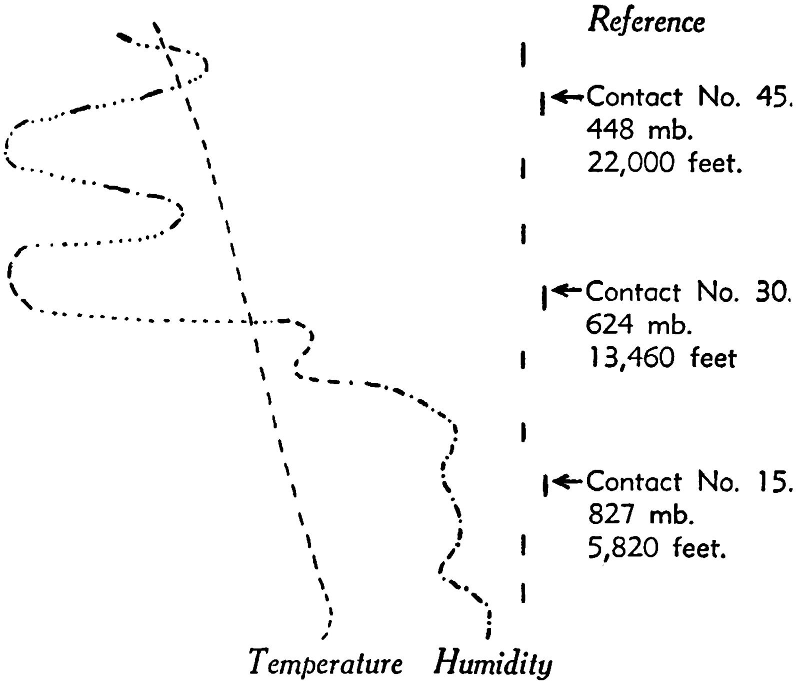
The pressure element is an aneroid cell which is connected to a multipoint switch connecting various resistors into the grid circuit of the modulating section of the transmitting unit. The switch consists of 80 strips of metal insulated from each other. The first four contacts are connected together and to a small relay which alternately connects a temperature and humidity element into circuit. The relay is a small electro-magnet with a light blade spring contact, when no current is flowing, i.e., switch arm is on insulated spacing of switch, the temperature element is in circuit. When the switch arm is on a contact the relay inserts the hygrometer unit and thus the humidity controls the signal. This action is repeated until the arm reaches the fifth contact when the temperature element is shorted and a fixed resistance is connected in circuit.

There are sixteen such sections in the switch. Every fifth contact gives a fixed "reference" frequency. To facilitate checking the number of the contact, every third reference contact inserts a lower resistance in the circuit and gives a "high reference" frequency. Every contact has a pressure value and the pressure corresponding to every "high reference" contact is found by calibration.

The temperature element is an electrolytic resistor as described in Section 15. This is lighter, and has a greater temperature coefficient than an equivalent metallic resistor; besides being cheaper to produce. This element presents a comparatively large surface, and has a rapid response to temperature changes.

The hygrograph employed is a multiple element type similar to that described in the supplement to Section 3. It has a rapid response (8 secs.) and does not necessitate the use of a separate variable resistor as does the hair hygrometer, and, owing to its rapid response, gives a more accurate humidity report.

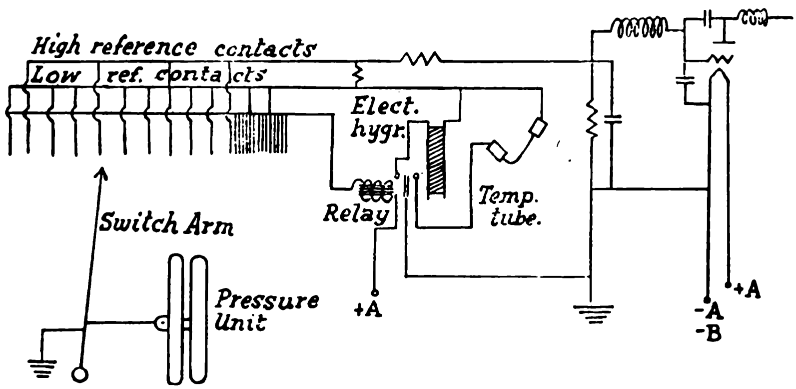
The radiated signals are received and analysed by a special type of receiver, which has a recording unit attached giving points on a chart which have to be connected by lines. Although a complete trace is not given, there is little chance of an error being made in completing the temperature and humidity graphs, the reference points being on the extreme right of the chart, and vertically above one another.



This is a copy of an actual trace obtained from a sounding made on a trial radiosonde. Notice the rapid response of the electric hygrometer.

The humidity trace can easily be traced on account of the uniform temperature lapse rate. In evaluating the humidity a special correction graph is used to allow for temperature variations.

By means of direction finding apparatus, the exact location of the balloon and radiosonde at any instant can be found, and thus the direction and velocity of the upper air can be determined at the same time.



Circuit of modulating section of the radio transmitter

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course

for

Meteorological Assistants

PART 3

Elementary Physical Meteorology

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course
for
Meteorological Assistants

PART 3

Elementary Physical Meteorology

ELEMENTARY PHYSICAL METEOROLOGY FOR METEOROLOGICAL ASSISTANTS

CONTENTS

SECTION 1

ELEMENTARY PHYSICAL METEOROLOGY

THE ATMOSPHERE

The atmosphere consists of two main parts, that near the surface of the earth in which the various changes take place, causing changes known as weather, and the second part, above, in which no such changes occur.

The lower atmosphere is called the troposphere and the boundary between this and the stratosphere above is called the tropopause.

The stratosphere is an almost uniform mixture of two gases—oxygen and nitrogen—with a very small percentage of ozone, which is very important on account of its effect on solar radiation.

The height of the tropopause varies with the season and also with weather phenomena; an average height is 35,000 feet.

The troposphere contains a mixture of many gases, in approximately fixed proportions but also contains water vapour, dust and industrial gases in varying proportions.

For the lower atmosphere the composition is approximately:—

Constituents present in approx. fixed proportions		**Constituents present in variable proportions**
Nitrogen	78·08%	Water vapour.
Oxygen	20·94%	Dust.
Argon	·94%	Smoke.
Carbondioxide ..	·03%	Industrial gases, etc.
Rare gases	·01%	

In meteorology we are concerned chiefly with the water vapour content of the atmosphere, but important uses and function of the more important constituents will be briefly mentioned.

Nitrogen: An inert gas until recently had no use but now by various chemical means is converted into nitrogen compounds from which are manufactured fertilisers and explosives.

Oxygen: (i) Oxygen is essential for the maintenance of animal life—heat and energy are produced by the oxidation of carbon compounds in the body the resulting carbondioxide finally being exhaled from the lungs.

(ii) Oxygen takes part in the processes of combustion, decomposition, rusting, etc., which are of immense practical importance, e.g., the greater part of the world's power is produced by the combustion (oxidation) of carbonaceous fuels such as coal, oil and wood.

Argon: The most plentiful of the "rare" gases, is isolated and used for filling electric lamps.

Carbondioxide: Is continually being added to the atmosphere as the result of breathing of animals and combustion of carbonaceous fuels and decay of organic matter. It is continually removed from the atmosphere by plant life for which it forms the principal food, and by solution in the sea, etc.; thus, except in industrial areas, the actual percentage value does not rise.

Water Vapour: The proportion of water vapour in the atmosphere varies considerably. One of the principal factors influencing the water vapour content is temperature and, hence, the water content will vary with latitude. Tropical air, in general, is warm with a high water vapour content. In high latitudes the air is cold with a low water vapour content. Average figures for the percentage by volume of water vapour in the air are:—

At Equator, 2·6%; 50° N., 0·9%; 70° N., 0·2%.

The other principal factor determining the amount of water vapour in the air is the past history and source of the air, e.g., whether it has recently been travelling over sea or land, i.e., whether it is maritime air or continental air.

The water vapour content of the atmosphere falls off rapidly with height, as would be expected since normally temperature also falls off with height, but other factors also cause the same result.

Dust: The dust consists mainly of small solid particles raised from the surface of dry ground by the wind. In addition small solid particles are provided by smoke and small particles of hygroscopic salts are produced by the evaporation of sea spray. Vast quantities of dust are also produced periodically by volcanic eruptions.

The presence of these fine dust particles in the atmosphere plays an important part in process of cloud formation as they provide nuclei on which the water vapour can condense, and also effects the transmission of radiant heat and light through the atmosphere.

SECTION 2

HEAT AND TEMPERATURE

Heat may be defined as one of the forms of energy. The Law of Conservation of Energy states that energy can neither be created nor destroyed. One form of energy may, however, be converted into another form, e.g., coal is burned in a boiler (chemical energy transformed into heat energy). Steam from the boiler drives a turbine (heat energy transformed into mechanical energy). The turbine drives a generator (mechanical into electrical). Power from the generator is consumed in a lamp (electrical into light and heat).

Temperature may be defined as that which determines the direction and rate of flow of heat. It may be described as a "heat level" and understood by analogy with gravitational level and electrical potential. Temperature is a relative term—an object which is hot by comparison with one object may be cold in comparison to another.

Usually a hot body is one which gives out heat to its surroundings and conversely a cold one absorbs heat from its surroundings.

Expansion: The general effect of a rise of temperature of a substance, whether solid, liquid or gas, is to cause expansion, different substances expanding by different amounts for the same temperature change. In the case of solids which have "shape rigidity" we get an increase of linear dimensions, i.e., an increase in length, breadth, etc. Liquids and gases, however, have no "shape rigidity," their shape depending on the shape of the containing vessel, hence in speaking of liquids and gases we speak only of the increase of volume.

A practical application of the expansion of solids when heated is the bimetallic thermograph which makes use of the difference in expansion between copper and invar steel.

Mercury Thermometer: In this instrument changes of temperature are indicated by the expansion and contraction of mercury enclosed in a glass container. A glass bulb is blown on the end of a piece of capillary tubing of uniform bore. Sufficient mercury is introduced to fill the bulb and part of the capillary tube. The capillary tube is sealed at the top, the space above the mercury and the top of the tube being evacuated. A rise in temperature causes expansion of the glass container and also expansion of the mercury. The expansion of the mercury, is, however, much greater than that of the glass and hence the mercury rises in the capillary tube.

Obviously, for the simple calibration of the thermometer, it is necessary—

(i) that the bore of the tube should be quite uniform; and
(ii) that the expansion of the thermometric liquid should be uniform, i.e., equal increases in temperature should cause equal increases in volume.

The first of these conditions is attained by careful manufacture and selection of the tubing. The second condition is satisfied very well by mercury the expansion of which is, for practical purposes, uniform. Other advantages of using mercury are: —

(i) It can be used over a wide range of temperature as its freezing point is — 40° C. while its normal boiling point is 356° C. Under higher pressures the boiling point can be considerably raised and in special thermometers the use of mercury may be extended to 550° C.

(ii) Mercury does not "wet" glass and can therefore be used in fine capillaries, and has a convex meniscus which enables the top of the column to be accurately determined.

(iii) Its ~~capacity~~ and silver colour enable it to be easily seen in fine bore tubes.
(iv) Being a metal it is a good conductor of heat and therefore changes of temperature are indicated without much lag.

Defects of Glass-mercury Thermometer: We have already stated that mercury has excellent properties as regards uniformity of expansion. Unfortunately, however, the same cannot be said of the glass container, the expansion of which is not uniform and which, moreover, varies from time to time according to its past history. Most of the defects of the mercury-glass thermometer arise therefore in the glass container. One common defect of these thermometers is a gradual rise of zero due to gradual contraction of the bulb which the manufacture leaves in a state of strain.

Graduation of Thermometer: For the graduation of thermometers to be used over ordinary ranges of temperature there are two easily reproducible "fixed temperatures" which may be used. These are—

(i) The melting point of pure ice under a pressure of one standard atmosphere; and

(ii) the boiling point of pure water under a pressure of one standard atmosphere.

Centigrade and Fahrenheit Scales: Two thermometer scales are in common use—the Centigrade and the Fahrenheit. On the centigrade scale the M.P. of ice is taken as 0°. and the B.P. of water as 100°, the interval between these two temperatures being divided into 100°. On the fahrenheit scale the M.P. of ice and the B.P. of water are 32° F. and 212° F., the interval between being divided into 180°.

Conversion of Centrigrade and Fahrenheit Temperatures: To convert a centigrade temperature to fahrenheit multiply by $\frac{9}{5}$ and add 32.

$$\text{e.g., } 25^\circ \text{ C.} = \frac{25 \times 9}{5} + 32 = 45^\circ + 32 = 77^\circ \text{ F.}$$

To convert a fahrenheit temperature to centigrade subtract 32 and multiply by $\frac{5}{9}$.

$$\text{e.g., } 86^\circ \text{ F} = (86 - 32) \times \frac{5}{9} = 54 \times \frac{5}{9} = 30^\circ \text{ C.}$$

Absolute Temperature: A scale of temperature, based on thermodynamic reasoning, may be derived with a zero corresponding to the absolute zero of temperature. On the centigrade scale this absolute zero corresponds to a temperature of — 273·2° C. Hence absolute temperature = centigrade temperature + 273.

e.g., 15° C. = 15 + 273 = 288° A.

Types of Thermometers: The various special types of thermometers are dealt with in the lectures on Meteorological Instruments.

Unit Quantities of Heat: The only unit of quantity of heat referred to in these notes will be the calorie. The calorie is defined as the amount of heat required to raise the temperature of 1 gram of water 1° C. (or A.).

States of Matter: Matter exists in three states—solid, liquid and gaseous. For example, ice, water and water vapour are the same substance in its three states.

A solid is a substance which at ordinary temperatures has a definite shape and volume and does not require a container.

A liquid has a definite volume and takes the shape of the containing vessel.

A gas has no definite shape or volume and tends to occupy all the available space.

SECTION 3

CONDUCTION, CONVECTION AND RADIATION

TRANSFERENCE OF HEAT

Heat may be transferred in three ways—conduction, convection and radiation. For the transmission of heat by conduction and convection a material medium is required, but no such material medium is required for radiant transmission, e.g., heat is transmitted from the sun to the earth through space by radiation.

CONDUCTION

Conduction is characteristic mainly of solid substances. Liquids are, as a rule, indifferent conductors (except mercury, a metal), while gases are very poor conductors. The best conductors of heat are the metals. Substances such as wood and paper are indifferent conductors. Bad conductors, which are commonly used to impede the transfer of heat, are referred to as insulators and are used for such purposes as insulating the walls of refrigerators, lagging steam pipes, etc. Typical insulators are asbestos fibre, rock, wool, fur, felt, charcoal, sawdust, granulated cork, etc.

In general, an insulator is a porous material containing much imprisoned air and it is mainly the very poor conductivity of the air which provides the insulation. An air space alone is rarely suitable for insulating as heat would be transferred by convection currents set up in the air. The ideal insulator is, of course, a vacuum such as is used in the construction of a thermos flask.

If we consider a uniform bar of a substance, say a rod of copper, the rate of conduction of heat along the rod is proportional to the cross section of the rod, and to the temperature difference between the ends of the rod and inversely proportional to the length of the rod.

Hence if the area of cross section is A square units, the length b units and the temperature difference between the ends $t_1 - t_2$, we have—

$$\text{Rate of flow of heat} \propto \frac{A\,(t_1 - t_2)}{b}$$

$$= \frac{KA\,(t_1 - t_2)}{b}$$

where **K** is called the thermal conductivity of the substance.

The following are some values of K at 18° C.

Copper—0·918 Cals./cm^2/sec.
Silver—0·974 Cals./cm^2/sec.
Aluminium—0·504 Cals./cm^2/sec.
Glass—2×10^{-3} Cals./cm^2/sec.
Air—$5{\cdot}4 \times 10^{-5}$ Cals./cm^2/sec.
Water—$14{\cdot}7 \times 10^{-4}$ Cals./cm^2/sec.

CONVECTION

Convection is characteristic of liquids and gases. Imagine a vessel of water placed over a source of heat. Heat is conveyed through the bottom of the vessel by conduction. The water along the bottom of the vessel is warmed, it therefore expands and so becomes less dense. The less dense warm water will therefore be displaced by the heavier colder water. Hence a circulation is set up of ascending warm (less dense) currents and descending cold (more dense) currents. The circulation is known as convection and is caused by the change in density of the liquid (or gas) which is a result of thermal expansion.

In meteorology, the transference of heat by large scale convection currents in the atmosphere is of the greatest importance. In everyday life we make use of convection in the heating of liquids, the circulation of water in heating and cooling systems, the ventilation of rooms by natural circulation of air, etc.

RADIATION

Radiation is the process by which heat can be transferred through empty space, as for example, the transfer of heat through space from sun to earth. Radiant heat is of the same basic nature as light, x-rays, wireless waves, etc., the difference between these different types of radiation being one of wave-lengths. The visible spectrum covers a band of wave-lengths from ·00004 cm.. (violet) to ·00008 cm. (red) Radiant heat wave-lengths range up to about ·006 cm.

The similarity between radiant heat and light can be readily demonstrated by showing that they obey the same laws of reflection and of refraction. They travel through space with the same velocity.

RADIATION, ABSORPTION AND REFLECTION OF RADIANT HEAT

All bodies are continually radiating heat, the radiation depending upon the temperature of the body and upon the nature of the surface of the body. Comparing surfaces at the same temperature it would be found that a dull surface is the best radiator, white or light coloured surfaces much worse radiators, while bright polished surfaces have the lowest radiating power.

Just as all bodies are continually radiating heat so also all bodies are continually absorbing heat radiated from other surrounding bodies. Just as the radiating powers of surfaces differ so also do the absorbing powers. Dull black surfaces absorb most readily and bright polished surfaces absorb least readily. In general, a surface will absorb part of the incident radiation and reflect the remainder, the relative amounts absorbed and reflected depending upon the nature of the surface and also upon the wavelength of the radiation.

In general, remember that good radiators are good absorbers —bad radiators bad absorbers.

DIATHERMANCY AND ATHERMANCY

A medium is said to be diathermanous to a thermal radiation if it transmits the radiation without any absorption. A substance is athermanous to a radiation if it absorbs the radiation instead of transmitting it. The terms are equivalent to the terms "transparent" and "opaque" when speaking of the transmission of light.

A most important effect is the fact that a medium may be diathermanous for radiation of some wave-lengths but athermanous for other wave-lengths. An important effect of the atmosphere is the green-house effect of some of the constituents. The green-house effect is as follows:—Much of the radiation from the sun is of short wave-length to which the glass roof of the green-house is diathermanous (transparent). Hence, radiant heat enters the green-house and is absorbed by the plants, etc., inside. The radiant heat which is re-radiated by the plants, however, is of long wave-length to which the glass is athermanous (opaque). Hence the glass acts as a one-way valve which admits radiant energy from without but prevents the passage from within, the result being the raising of the temperature inside the green-house.

The water vapour content of the atmosphere provides a similar glass-house effect for the earth, being diathermanous for most of the radiation from the sun but almost completely athermanous for the long wave-length radiation from the earth. The cooling of the earth by radiation is therefore largely controlled by the water content of the atmosphere in the manner explained above and also by the reflecting properties of clouds.

SOLAR RADIATION, INCOMING RADIATION

All happenings in the atmosphere are due directly or indirectly to solar radiation. Sources of radiation other than the sun are insignificant, e.g., the heat energy from other stars and from the interior of the earth is negligible compared with solar radiation.

The energy output of the sun is not quite constant as is shown by the appearance from time to time of sunspots, areas on the surface of the sun which are at a lower temperature than their surroundings. The variation in the output of energy is, however, small and probably less than 1%.

About half the radiant energy received from the sun is of the shorter wave-length of the visible spectrum (light), the rest being radiation of longer wave-lengths (radiant heat).

INFLUENCE OF ATMOSPHERE ON INCOMING RADIATION

Even if clear the atmosphere absorbs some of the incoming

radiation. With a clear atmosphere and a vertical sun only about 80% of the energy reaches sea level, the rest being absorbed or scattered by the atmosphere. The reduction of the incoming radiation will be greater the greater the length of the air path traversed. Hence the lower the elevation of the sun the longer the air path and so the greater the absorption and scattering of energy.

On an average 43% of the solar radiation reaching the atmosphere is reflected back to space, 15% is absorbed in the atmosphere and 42% actually reaches the surface.

Two effects limit the amount of solar radiation reaching the earth's surface:—(i) Absorption of certain wave-lengths by some constituents of the atmosphere—chiefly water vapour and carbon dioxide, and (ii) the scattering and diffuse reflection of radiation by dust particles and gaseous molecules. The longer wave-lengths can be scattered only by the larger dust particles but the shorter wave-lengths of the blue region of the spectrum can be also scattered by gaseous molecules. Hence the shorter wave-lengths of the blue end of the spectrum are freely scattered while the longer wave-lengths of the red end of the spectrum are much less scattered.

This phenomenon accounts for the blue colour of the sky and the red colour of a dust storm. Of the scattered radiation part reaches the earth and part is lost to space. The amount of scattered sky radiation received by the earth is quite considerable under certain (e.g., hazy) conditions and with low elevations of the sun the earth may receive more scattered radiation than direct radiation and hence in latitudes greater than 60° in winter the sky radiation is of the greater importance.

EFFECT OF CLOUD, SNOW AND WATER ON INCOMING RADIATION

Clouds interfere considerably with incoming radiation owing to their high reflecting power or albedo, as it is called. Three-quarters of the radiation falling on a cloud is reflected. Similarly snow has an equally high reflecting power. The reflecting power of water depends on the angle of incidence of the incoming radiation. For oblique incidence a considerable part of the radiation is reflected. Since 70% of the surface of the globe is water covered this effect is an important one. The great reflecting power of snow and of water when the elevation of the sun is low is very disadvantageous to high latitudes where most of the surface is snow or water covered.

OUTGOING RADIATION

The outgoing radiation of the earth, being radiation from a relatively cool body, is non-luminous radiation of long wave-lengths. The constant temperature of the earth indicates that there is equilibrium between incoming and outgoing radiation.

Calculations in which the effect of the atmosphere is neglected show that the mean temperature of the earth should be about 277° A., whereas the actual mean temperature is about 287° A. Hence the atmosphere acts as a blanket to the earth and has the effect of raising the temperature 10° A.

About 80% of the outgoing radiation from the earth is absorbed by the atmosphere, the remainder being lost to space. The absorption of the outgoing long wave-length radiation is mainly due to the water vapour content of the air, which, as already stated, is athermanous to most of the long wave-length radiation. Hence, polar air, having a lower water content, is much more transparent to outgoing radiation than the warm moist tropical air, which is another disadvantage for high latitudes. Also we now see why low minimum temperatures are recorded in clear dry anti-cyclonic weather. Clouds also have a considerable controlling effect over the outgoing radiation owing to absorption and reflection of the outgoing radiation by the cloud cover. With an overcast sky the outgoing radiation lost to space is only about one-fifth of what it would be with a clear sky. Hence low minimum temperatures do not occur with overcast conditions.

It may be noted that for the long wavelength radiation emitted by the earth, most surfaces, even snow, have a good transmitting power. The high reflecting power of snow for the incoming radiation and the good transmitting power for the outgoing radiation accounts for the sustained low temperatures of high latitudes.

Another point which may be noted is that more than one-sixth of the total incoming radiation is consumed as latent heat in evaporating water. This heat is, of course, transferred to the atmosphere when condensation of the water vapour occurs.

Another point of interest with regard to the absorption of incoming radiation is the effect of ozone which occurs in the upper atmosphere (stratosphere). Ozone has the power of absorbing the very short ultra violet wave-lengths from the sun's radiation. Since these short wave-lengths are destructive to living tissues it would seem that the presence of the ozone in the stratosphere makes life on earth possible.

SECTION 4

GAS LAWS, VAPOUR PRESSURE

Pressure is defined as force per unit area and is generally expressed in terms of weight, e.g., lbs. wt. per sq. inch; grams wt. per sq. cm. These gravitational units are not, of course, of constant magnitude owing to the variation of the acceleration due to gravity at different parts of the earth's surface.

In absolute units pressure must be expressed in terms of the absolute units of force, i.e., in poundals or dynes.

Volume is the space occupied by an object and is expressed in cubic units.

Boyle's Law expresses the relation between the pressure and volume of a given mass of gas when the temperature is kept constant, as follows:—

If the temperature remains constant then the volume of a given mass of gas is inversely proportional to the pressure of the gas.

$$\text{i.e., } V \propto \frac{1}{P}$$

$$\text{i.e., } V = \frac{K}{P}$$

i.e., $PV = K$ where K is a constant.

Charles' Law expresses the relation between the volume and the temperature of a given mass of gas when the pressure is constant.

If the pressure remains constant then the volume of a given mass of gas increases by a constant fraction (1/273) of its volume at 0° for each degree centigrade rise in temperature, or in symbols—

$V_t = V_o \left(1 + \frac{1}{273}.\ t\right)$ where V_o and V_t are the Volumes at 0° C and t° C. respectively.

Charles' Law may be expressed more simply in terms of absolute temperature; thus we have—

$$V_t = V_o \left(1 + \frac{1}{273}.\ t\right)$$

$$\text{i.e., } \frac{V_t}{V_o} = \left(1 + \frac{1}{273}.\ t\right)$$

$$\text{i.e., } \frac{V_t}{V_o} = \frac{273 + t}{273}$$

But we have seen before that 273 + t is the temperature t° C. on the absolute scale—

$$\text{thus } \frac{V_t}{V_0} = \frac{T_t}{T_0} \text{ where T represents absolute temperatures.}$$

Hence, Charles' law may be expressed as follows:—

If the pressure remains constant then the volume of a given mass of gas is directly proportional to the absolute temperature.

Since density is inversely proportional to volume we may also state the above result as—

If the pressure remains constant, then the density of a gas is inversely proportional to its absolute temperature.

The laws of Boyle and Charles may be combined to give the Gas Law expressed as—

$$PV \propto T$$

or $PV = RT$ where R is a constant, the actual value depending upon the units used for P, V and T.

Vapour Pressure: Imagine the evaporation of liquid in a closed vessel, say a stoppered bottle into which is introduced some water. The molecules of water vapour will move rapidly about in the space some colliding with the walls of the bottle, setting up a pressure on the walls, and some striking the water surface and returning again to the water.

Hence we have two opposing tendencies. A stream of molecules leaving the water and a stream of molecules returning to the water. Finally the concentration of vapour molecules in the space above the liquid becomes such that a state of Dynamic Equilibrium is reached when the rate at which water molecules leaves the liquid (evaporation) becomes equal to the rate at which vapour molecules return to the liquid (condensation). When this equilibrium state is reached the space above the liquid is said to be **saturated** with the vapour of the liquid and the pressure which the vapour produces on the containing vessel by the bombardment of the moving molecules against the containing walls is called the **Saturation Vapour Pressure.**

The amount of vapour which a given space can contain before becoming saturated depends upon the temperature. The higher the temperature the greater the amount of vapour required to saturate a given space and therefore a greater vapour pressure is exerted. Thus warm tropical air has a much greater capacity for water vapour than has cold polar air.

Dew Point: We have just stated that the amount of water required to saturate a given space depends upon the temperature. Hence, if a mass of unsaturated air is cooled down it will finally reach a temperature at which the water vapour contained in it is sufficient to saturate it and a further slight cooling will cause

part of the vapour to condense. **The temperature at which the air becomes saturated and condensation starts is called the Dew Point.** It is in this way, by the cooling of air to such a temperature that its water content is sufficient to saturate it, that cloud formation starts in the upper air, and dew, frost and fog formation starts at ground level.

Relative Humidity: Relative Humidity is defined as the ratio of the vapour pressure exerted by the water vapour actually present in the air to the vapour which would be exerted if the air were saturated at the same temperature.

$$\text{R.H.} = \frac{\text{V.P. actually exerted at time}}{\text{Saturation V.P. at Air Temperature}}$$

Since the mass of water vapour present is approximately proportional to the vapour pressure exerted the relative humidity may be defined approximately as the ratio of the mass of water vapour present in a given volume of air to the mass of water vapour which would be present if the air were saturated.

$$\text{R.H.} = \frac{\text{mass of water vapour present in given volume of air}}{\text{mass of water vapour required to saturate that volume}}$$

Accurate determinations of relative humidity are made with a dew point hygrometer with which is determined the dew point, that is, the temperature at which the water vapour in the air is sufficient to saturate it.

Hence, suppose on a given occasion, the temperature of the air is 25° C. and the dew point is found to be 14° C., then we have—

$$\textbf{R.H.} = \frac{\text{V.P. exerted by the water vapour in the air}}{\text{V.P. which would be exerted if the air were saturated}}$$

But the amount of water vapour actually present in the air is sufficient to saturate it at dew point 14° C.

$$\text{Hence R.H.} = \frac{\text{SATURATION PRESSURE AT 14° C.}}{\text{SATURATION PRESSURE AT 25° C.}}$$

These pressures are found from vapour pressures tables to be (A.O. Handbook, p. 132) 0·468 and 0·926 inches of mercury respectively.

$$\text{Hence R.H.} = \frac{\cdot 468}{\cdot 926} = 0{\cdot}50 \text{ or } 50\%.$$

(The practical determination of Relative Humidity is dealt with in the lectures on Instrumental Meteorology.)

Evaporation: Consider a liquid, say water, exposed in an open vessel, say a saucer. As its component molecules move about some will escape from the liquid to the space above the surface from which they will be swept away by air currents before they can

return to the liquid. In this way the liquid gradually disappears —we say it has evaporated. The water has changed from the liquid to the gaseous state, the resulting water vapour being now mingled with the air.

Rate of Evaporation: The rate of evaporation increases with rise of temperature. An increase of temperature brings about an increase in the velocity of the moving molecules and thus enhances the chance of a molecule escaping from the liquid. For rapid evaporation, also, it is required that the vapour molecules be carried away before they can return to the liquid, hence it is obvious that a hot, windy day provides the best conditions for the rapid evaporation of water.

Cooling Caused by Evaporation: We have seen before that the conversion of a liquid into vapour involves the absorption of much heat (latent heat) to bring about the change of state. When a liquid evaporates this heat is absorbed from itself and its surroundings and hence evaporation is always accompanied by a cooling effect—the more rapid the evaporation the more marked the cooling effect. This cooling by evaporation (in other words the absorption of latent heat) is the basis of the action of the wet bulb thermometer.

SECTION 5

LAPSE RATES AND STABILITY

(a) TEMPERATURE LAPSE RATE

The lower air is heated not directly by the rays of the sun but through contact with the earth's surface. The sun is continually sending out radiation and it is only when the sun's energy in this form is absorbed by some material body that it is converted into heat. That part of the sun's radiation which passes unabsorbed through the atmosphere is absorbed by the earth's surface which is warmed and then heats the air in direct contact with it by the process of conduction. The heat so transferred to the lowest layers of the atmosphere is passed upwards by the vertical movement of the heated air under the process of convection. Thus the temperature of the air close to the ground begins to rise during the morning until it reaches a maximum. As the temperature of the air at some height above the surface (say at 400 feet) is raised by the arrival of heated air raised by convection, the maximum temperature aloft (which will be lower than that at the surface) will be reached later in the day.

As most of the heating of the air takes place close to the surface the temperature of the air generally falls off with height, on the average at the rate of 1° F. for each 300 feet of altitude. The rate of fall of temperature with height is called the "Temperature Lapse Rate," so that we say the average "lapse rate" is 1° F. per 300 feet.

In certain situations the temperature of higher levels is found to be higher than that at lower levels; there is then an "inversion."

Inversions are frequently formed in the lower levels of the atmosphere on cold, quiet nights owing to cooling of the ground by the radiation of its heat to a clear sky and the subsequent chilling of the air in contact with the surface, which may produce dew, fog or frost depending upon the temperature reached and the wind velocity at the time.

Stability and Instability

Air is said to be stable or in stable equilibrium if on displacement it tends to return to its original position; if on displacement the air keeps moving, that is the displacement is increased, it is said to be unstable. Neutral equilibrium is such that on displacement there is no tendency to either increase or decrease the displacement.

Adiabatic Tmperature Changes

Consider a "bubble" of air in the atmosphere. It is obvious that—

(i) if the "bubble" is colder than the surrounding air it will sink,

(ii) if it is warmer than the surrounding air it will rise; and
(iii) if it is at the same temperature as the air it will remain stationary.

When a "bubble" of air rises it will expand owing to the reduction of the pressure at the higher levels. This expansion will cause the temperature of the "bubble" to fall. If, in addition, while the "bubble" is rising, no heat is transferred either from the atmosphere to the "bubble," or from the "bubble" to the atmosphere, the "bubble" is said to behave adiabatically, and the rate at which its temperature falls off with height is said to be the "dry adiabatic lapse rate." The adiabatic lapse rate for dry air is about 1° C. per 100 metres or 5·4° F. per 1000 feet of altitude. Thus, if the lapse rate in the surrounding air is greater than 5·4° F. per 1000 feet, the atmosphere at a particular level will be cooler than the "bubble" and so the "bubble" will go on rising, that is, the conditions will be unstable. On the other hand, if the lapse rate in the surrounding atmosphere is less than the dry adiabatic lapse rate the atmosphere at a particular level will be warmer than the "bubble" which will therefore fall, that is, the conditions will be stable. The smaller the lapse rate (i.e., the less the temperature of the air falls with height) the more stable will be the atmosphere, i.e., the greater will be the tendency to return any displaced "bubble" to its original level. This means that the smaller the lapse rate the more difficult it is for "bubbles" of air to rise or fall within the atmosphere. In the extreme case, when there is an inversion, the gusts in the wind due to the roughness of the ground almost cease because the vertical motion of the eddies is strongly damped because of the low temperature lapse rate in the air.

Although the above remarks apply to perfectly dry air, they also apply to air which contains water vapour but which is unsaturated (i.e., if its temperature is NOT that of the Dew Point), since water vapour behaves as an almost perfect gas.

Adiabatic Lapse Rate for Saturated Air.

If a "bubble" of air is saturated (that is, if its temperature is the same as its dew point) expansion and cooling will be accompanied by condensation which liberates heat, so that if such a "bubble" rises adiabatically (i.e., giving and receiving no heat from the surrounding atmosphere) its temperature will fall off

more slowly than if condensation did not take place. The fall of temperature of the "wet bubble" in such a case is called the "wet (or saturated) adiabatic lapse rate" and is about 2·7° F. per 1000 feet. In order that saturated air starting just a little warmer than its surroundings should rise, and keep rising, the temperature of the surrounding atmosphere must fall more than 2·7° F. per 1000 feet, i.e., the lapse rate must be greater than the "wet adiabatic lapse rate."

The growth of cumulus cloud is checked near the height where the temperature lapse rate is less than this amount.

With a downward displacement saturated air warms and becomes unsaturated and thus warms at the dry adiabatic lapse rate.

Condensation Height

The "condensation height" is the height to which a "bubble" of "dry" air would have to be lifted adiabatically (i.e., without giving or receiving heat from the surrounding atmosphere) before its temperature fell to the dew point. The height of condensation is given approximately by multiplying the difference between the dry bulb thermometer of the air at the surface and the initial dew point (at the surface) in degrees F. by 186. This allows for a fall of temperature of 1° F. per 186 feet (the dry adiabatic lapse rate). Estimation of the condensation height will give the height at which clouds may begin to form and thus the height of the cloud base.

SECTION 6

FOG, DEW, FROST

The term fog is used to describe the conditions when the visibility is less than 1,100 yards. Strictly the term fog should only be used when this reduced visibility is caused by cloud, i.e., the air is saturated. Sometimes the term is used when the visibility is reduced by smoke or dust to the limit of 1,100 yards.

Since a true fog is a cloud, it should be formed in the same manner as a cloud, that is by saturation of the air. This can be caused in one or more of the following ways:—

1. Cooling to or below dew point.
2. Increase in water vapour content by—
    (a) evaporation of water into the air;
    (b) mixing of two nearly saturated air streams at different temperatures.

Saturation having been reached, two more conditions must be fulfilled—

3. Nuclei such as smoke particles must be present to cause condensation to take place.
4. Slight turbulence is required to keep the water drops in suspension in the lower layers of the atmosphere. (Too much turbulence will dissipate the fog.)

This requires—

5. Stable stratification which will partially but not completely damp out turbulence.

This signifies—

6. Small lapse rate (less than the s.l.r.) or even an inversion.

Dealing with the saturation methods in turn it will be found that cooling to or below dew point may be caused by two methods —non-adiabatic and adiabatic.

Non-adiabatic cooling is caused by heat being removed from the air by outside means, while adiabatic cooling is caused solely by pressure changes of the air and no transfer of heat takes place between the air and the surroundings. Non-adiabatic cooling is the more important and can be caused by—

(A) Radiation from the surface. This is mainly a nocturnal process which cools the air in contact with the surface by conduction; if there is turbulence the cooled air is replaced by warm air and so more and more air is cooled. This process is gradual and the degree of cooling produced depends upon the rate of the radiational cooling and the length of time the air remains in contact with the cooled ground.

The rate of radiational cooling depends upon—

(a) the state of the sky;

(b) the relative humidity of the atmosphere.

A clear sky permits greater radiation than a clouded one, but very moist air restricts the outgoing radiation and so a compromise must be made. The relative humidity must be sufficiently high to enable the air to become saturated at the temperature likely to be produced by radiational cooling.

Clear skies are mostly observed during anti-cyclonic weather when also stable stratification predominates.

Radiation fogs are thus usually observed in or near anti-cyclonic centres in winter. The most effective conditions for formation of a radiation fog are a clear night following a cloudy day during a period of anti-cyclonic weather.

(B) Advection can produce sufficient cooling when there is a large temperature difference between the air and the surface. Fog may be produced in one of two ways by advection—

(a) Warm air over cool surface—air is cooled to cause saturation;

(b) cold air over a warm water surface.

Advection fogs of type (a) are most frequent over large areas of water in summer and over the land in winter as they require horizontal contrasts in temperature. These fogs may form at any time of the day, especially over the sea; over the land they are not likely to be dense in the afternoon.

Advection fogs of type (b) are not formed by cooling but by increasing the water content of the air. They are most frequently found over warm seas in the vicinity of sources of extremely cold air (such as arctic regions). These fogs may also be formed by warm rain falling through chilled air which usually indicates warm frontal rain and also that the air beneath the cloud is almost saturated. This type of fog will form in strong winds if the temperature difference is sufficient. They may be seen over rivers and lakes when air gravitates from cooling land over the water surface. In this case they are not very deep and do not extend far over land but may render island aerodromes useless.

Adiabatic cooling is usually insufficient on its own to produce fog but may be enough to complete or assist a non-adiabatic process. The main adiabatic processes are:—

(C) Local pressure reductions—on lee sides of ranges and hills—usually form lenticular type cloud which to an observer there would be fog. Local pressure changes are insignificant at sea level.

(D) Vertical motion, on windward sides of topographical features, causes "upslope fog" which to an observer at sea level will be a cloud. In such a case down drafts such as light katabatic winds may bring such fogs back down into the valleys provided temperature contrasts are not too severe.

It will be noticed that adiabatic cooling can only be produced at sea level by a decrease of air pressure without the air leaving the surface. This is a remote possibility.

Mixing of two nearly saturated air masses at different temperatures can only produce a thin fog since condensation will cause liberation of latent heat with a consequent rise in temperature. Sea breeze fogs are caused in this way. This method of saturation is more likely to produce cloud than fog.

Fogs in Industrial Areas: Condensation can take place on hygroscopic nuclei before full saturation of the air has been reached. As these nuclei are often present in industrial areas these areas are more prevalent to fog than areas with non-hygroscopic nuclei. Dense fogs, however, always require full saturation.

The dissipation of fog can be effected by direct heating but is more often due to the initiation of turbulence or convection which tends to lift and finally dissolve the fog. An estimate of the time of dissipation can be formed by **considering the probable rise** of surface temperatures.

MIXING PROCESSES

Particularly in the lower atmosphere mixing by rising and falling movements (eddies, turbulence) takes place more or less thoroughly throughout a range of height, generally of 1,000 feet or so, but sometimes extending to 15,000 feet or even 30,000 feet (in duststorms and Cb.). At the other extreme mixing may be completely absent over a smooth surface, in a calm or light wind and with an inversion of temperature). When the atmosphere is sufficiently moist, it has a dry adiabatic lapse rate up to the condensation level, and a lapse rate greater than the wet adiabatic for some thousands of feet above that, great Cu. form, and the mixing takes place through the mechanism of large convectional cells. From what has been said above it can be realised that **mixing** takes place freely when the lapse rate is **large,** is greatly retarded by a low lapse rate, or may even be stopped by an inversion. The guiding principle in considering mixing is that it **tends to produce uniformity of distribution of the element being mixed.**

Consider the mixing of (1) dust; (2) water vapour; and the effect of mixing on (3) wind structure; and (4) temperature. These are important in explaining duststorms, fogs, Sc. cloud, the increase of wind velocity with height, the variation of wind direction with height, and gustiness. It can thus be seen that the mixing process is one of the most important in making "weather."

The Mixing of Water Vapour

Water vapour is added to the atmosphere by evaporation from the surface and then distributed upwards by mixing. It is clear that, in general, the water vapour content decreases with height and that mixing tends to make the distribution more uniform, that is, **to increase the content in the higher levels.**

Consider a case when there is an inversion or low lapse rate at a height of a few thousand feet above air which has a lapse rate near the dry adiabatic. There will be considerable mixing up to the level of the low lapse rate (or inversion) and water vapour will accumulate at that level because it cannot penetrate further into the more stable higher levels. This is one of the factors which may cause the formation of Sc. cloud in moist air streams. Another illustration is found where a moist stream moving over water slows down. Turbulence (and mixing) is then mainly confined to the lowest layers and whatever further water vapour is added remains in the lowest levels. If now the stream moves over **cold** land in the early morning, or in winter, fog or low stratus may form.

The Effect of Mixing on Wind Structure

The effect of mixing is to tend to make the wind current more uniform, that is, to tend to make the wind speed and direction uniform in the lower layers. Surface friction has the effect of (1) reducing the wind at the surface; (2) with other factors, of making the surface wind direction deviate from the above; and (3) forming eddies and gusts in the winds. The stronger the speed the greater is the surface frictional effect.

If mixing is slight, as on occasions of low lapse rates, when vertical motion is difficult, then (1) the eddies and gusts that accompany them are damped out; and (2) there is little tendency to uniformity in the vertical wind structure.

Thus, on a cold winter's morning with a low lapse rate even when the wind at 3,000 feet is 20 m.p.h., the surface wind may be light with a few gusts and the direction of the wind at the surface may make a large angle with the wind at 3,000 feet.

At the other extreme, in a southerly maritime stream with a large lapse rate, there is a considerable tendency to uniformity in the wind speed and direction and gusts (and even squalls if Cu. are well developed) are marked. It is now easy to explain the diurnal variation of wind at the surface over the land. Why it this absent over the sea?

The Mixing of Temperature

Generally the effect of mixing alone is to **cool the top of the turbulent layer of the atmosphere** and to tend to make the lapse rate approach the dry adiabatic in unsaturated air. It is difficult

to explain this without going deeply into the matter. The effect is to add another factor to those causing Sc. cloud. Thus, in a moist stream with a low lapse rate (or an inversion at a few thousand feet) mixing or turbulence tends to **cool** the upper layers and to **increase** the moisture content there, thus aiding the formation of Sc. Such streams are generally over the sea or coming from the sea.

The Mixing Effect in the Formation of Fog or Low Stratus

Whether the fog is formed by the cooling of the air by radiation from the ground on quiet clear nights, or by moist air moving over a cold surface it is mixing (or **slight** turbulence) which spreads the cooling upwards to increase the vertical extent of the fog; otherwise the cooling might be confined to a layer a few feet thick.

In the formation of low stratus in moist streams moving over a cold surface it is the mixing (or turbulent motion) that is required to produce sufficient vertical lifting to form the cloud. Thus, until the wind rises it may be clear, but soon afterwards low stratus forms and this cloud layer rises gradually as the surface is further heated and the condensation level is lifted (by convection). Afterwards, the stratus breaks and, if there is a low inversion above, the remainder of the day may be clear.

DEW

When the earth's surface or objects on the earth's surface become cooled to a temperature below the dew point, moisture is deposited on them in the form of dew. Such a cooling is caused by nocturnal cooling as a result of radiation. Conditions are most favourable for the formation of dew on a clear night when the air is fairly still. A clear night ensures maximum radiation, and still air ensures that the air in contact with the earth's surface will be cooled, whereas any appreciable wind continually brings new air into contact with the radiating surface and so maintains its temperature above dew point. Dew is more abundant in valleys, where the air becomes cold and stagnant, than on high ground where the air is usually in motion.

FROST

If the temperature of the radiating surface falls below freezing point, **and at the same time below the dew point** of the surrounding air, the water vapour passes directly from the vapour to the solid state and a deposit of ice crystals is formed. Such a deposit is known as hoar frost. If dew forms, and further cooling occurs and the temperature falls below freezing point, a clear glazed frost results. Frost, like dew, is more prevalent in valleys than on higher ground, since cold air, on account of its greater density, gravitates down the valley slopes and lies stagnant at the bottom, thereby increasing the cooling effect of the ground.

SECTION 7

SUPER-COOLED WATER IN THE ATMOSPHERE

It is a matter of common laboratory experience that water can be cooled far below its freezing point without solidification taking place. It is also well known that the super-cooled liquid is in an unstable state and if seeded with a particle of the more stable solid phase—ice—solidification of the super-cooled water will progress rapidly until the latent heat liberated in the change of state raises the temperature to the normal freezing point when equilibrium will be established between the solid and the liquid phases.

It is also well known that agitation of the super-cooled water will also result in upsetting the unstable equilibrium and will cause solidification to occur. In the case of solidification being caused by agitation it is found that microscopic crystalline nuclei make their appearance at different parts of the liquid and then grow. It appears likely, therefore, that the agitation assists in the re-arrangement of the molecular aggregates to the more stable state of these crystalline nuclei from which the transformation proceeds.

When damp air rises so that water condenses into liquid drops which are subsequently carried up to heights where the temperature is below 0° C., the droplets do not immediately freeze but remain in an unstable super-cooled state. Clouds of liquid drops have been observed at temperatures as low as — 40° C. According to Findeison, at temperatures a little below freezing point water droplets predominate in a cloud, but at temperatures below —10° C. ice particles predominate.

Condensation in the form of super-cooled water droplets at temperatures below freezing point has frequently been observed, in circumstances in which it is not possible to explain it, as water condensed above freezing point and subsequently super-cooled. If the idea, that the salts of evaporated sea-spray form the principle nuclei of condensation, is accepted then we have to consider each cloud droplet as a solution.

The existence of these "solution droplets" accounts for the presence of water at temperature below 0° C., but of course a droplet whose temperature is below 0° C. solely on account of the depression of the freezing point by the presence of a dissolved solute is not a super-cooled droplet in the sense that it would solidify on mechanical agitation. The real super-cooling is caused by the initial alignment of molecular aggregates, necessary for solidification, being delayed.

THE ICING OF AIRCRAFT BY SUPER-COOLED WATER

When an aircraft flies through a cloud of super-cooled water drops, any drop which strikes the leading edge of a wing will have its unstable equilibrium state upset by mechanical agitation and part of the drop will freeze, the latent heat produced raising the remainder of the drop to 0° C.

Imagine 1 gram of water at — 8° C. Now since the latent heat of fusion of ice is 80 cals. per gram, the solidification of 1/10th gram will liberate 8 cals. of latent heat, which is sufficient to raise the temperature of the whole gram to 0° C. Hence on impact 10% of the water freezes and the other 90% streams back across the surface of the wing.

The fraction of each drop which freezes on impact obviously depends on the degree of super-cooling. If the initial temperature were — 16° C. then 20% would freeze on impact and so on.

Now if it were only the portion of the water which freezes on impact that concerned us, the remaining water running off as water, the icing of aircraft would rarely be serious. However, this is not the case, and it is because a large portion of the remaining water also freezes that icing conditions are so hazardous. The nearer the temperature to 0° C. the greater the proportion of clear ice. Conversely, the amount of white ice or rime deposited immediately on impact is greater the lower the temperature. This type of icing is not so dangerous as it may be shaken off by vibration of the plane. The more dangerous types of ice accretion, when clear ice is formed, occur mainly between temperatures from 35° F. to 10° F.

Consider the gram of water 10% of which froze on impact, 90% being distributed as liquid water at 0° C. over the wing surface.

Over this water at 0° C. there is a saturation vapour pressure of 6·11 millibars, whereas the surrounding cloud air has a vapour pressure corresponding to — 8° C., which is only 3·12 millibars. Hence evaporation will take place from the water surface on the plane with the considerable cooling effect caused by the absorption of latent heat of vaporisation; this cooling is so considerable that most of the water will be frozen. Consider now the 0·9 gram of liquid water left after the original impact.

Take the latent heat of evaporation = 600 cals. per gram.
Take the latent heat of fusion = 80 cals. per gram.
Then let x grams of water evaporate leaving ·9 — x grams of ice.
Then latent heat absorbed by the evaporation = 600x cals.
The latent heat liberated by the solidification = 80 (·9 — x).

$$\text{Hence } 600x = 72 - 80x.$$

$$x = \frac{72}{680} = \cdot 11 \text{ gram.}$$

Hence it is necessary for only 11% of the original gram of water to evaporate to convert 89% into ice.

Just as the fraction of the water which freezes on impact depends on the degree of super-cooling, so also does the rate of evaporation of the remaining water depend on the degree of super-cooling. For example, if the cloud temperature were — 20° C. at which temperature the saturated vapour pressure is 1·04 mb. the rate of evaporation from the water surface will be greater than at — 8° C. at which temperature the saturation vapour is 3·12 mb.

It should be noted that in these examples relative humidities of 100% have been assumed. Actually the humidity is usually much lower and clear ice formation has been observed with values ranging from 51% to 100%, the average being about 90%· Under such conditions there would exist a still greater difference between the vapour pressure over the water surface and in the free air, with corresponding increase in the rate of evaporation.

This consideration would suggest that icing would take place more readily when the aircraft is flying through portions of a cloud or fog where the relative humidity is lower. This is in accordance with the observed rapid formation of ice as the plane emerges from cloud into the comparatively clear air just above or below.

A few instances of icing have been reported above freezing point. This does not often occur but is theoretically possible if the relative humidity within the cloud is less than 100%, so that there is a difference between the saturation pressure of water vapour at the given temperature and the vapour pressure in the air. About 2° C. is about the limit for this type of formation. At 2° C. and with a R.H. of 90% there would be a difference of vapour pressure of ·705 mb. Of course, very little ice would form under such conditions. On the other hand, considerable ice may be formed in cloud at 0° C. at which temperature water may be frozen by the absorption of latent heat caused by the evaporation of about 12% of the water.

Hence cloud at 0° C. must be considered dangerous as well as cloud at temperatures below freezing point.

HAIL

Hail consists of hard pellets of ice of various shapes and sizes, which fall from cumulo-nimbus cloud and are often associated with thunderstorms. Recorded weights range up to over 2 lbs. In the rapidly ascending current of a cumulo-nimbus cloud the rain drops are carried upwards by the rising air. If the rising current exceeds 25 feet per second all the condensed water is retained in the cloud. Although freezing level is usually reached within

13,000 feet of the surface in temperate latitudes, ice crystals are not immediately produced, however, but water drops in a super-cooled condition. Near the top of the cloud, however, ice crystals appear and grow into soft white pellets by condensation directly from vapour to solid. When such a pellet attains sufficient size for it to fall through the ascending air current, it will start to fall through the cloud and in doing so meets the super-cooled drops of water at the lower levels. These freeze on coming in contact with the ice pellets and imprison a quantity of air in the process, thereby surrounding the pellet with a layer of opaque white ice. In the lower part of the cloud the hailstone encounters raindrops not in the super-cooled condition; these freeze on the pellet comparatively slowly, surrounding it with a coating of clear ice.

If a hailstone is split open these different layers can be seen. Sometimes the hailstone is carried up again, in violent vertical currents, to the top of the cloud and the whole process may thus be repeated several times. Thus, when the hailstone finally reaches earth it consists of alternate layers of soft white and clear hard ice. This structure may be found on splitting open large hailstones.

In winter, when freezing point is reached at a low level, there may be no region of non-super-cooled drops in the lower part of the cloud. In this case the hailstones consist of soft ice only and are known as soft hail.

PHYSICAL CONDITIONS FOR ICE FORMATION IN THE ATMOSPHERE

(Extract from Paper by Dr. W. Findeisen, 13/10/'38)

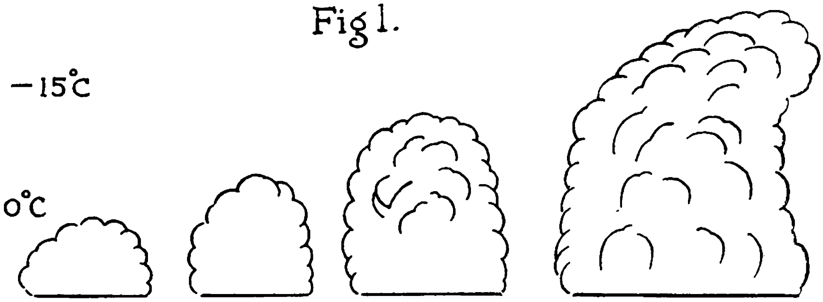
Ice formation is deposited on parts of an aeroplane when flying through air which contains drops of super-cooled water. The super-cooled drops on meeting the frontal edges of an aeroplane are caused to freeze and form a layer of ice.

Super-cooled water drops are present in super-cooled clouds and in super-cooled rain. In clouds which contain ice crystals only, there is no danger of ice formation as the particles do not adhere to the surface of the aeroplane parts.

Water clouds are produced by the condensation of the water vapour contained in the atmosphere on condensation nuclei. Water clouds can form not only at temperatures above zero, but also at much lower temperatures and certainly at all the temperatures likely to be encountered within the normal height range of present day flying. Ice clouds are produced by the sublimation of water vapour on sublimation nuclei which, unlike the condensation nuclei, are solid and insoluble in water. Below a certain temperature, which mostly lies at about — 15° C. to — 20° C., ice clouds are always formed in place of water clouds so long as sublimation nuclei are present.

The super-posed stratification of ice and water clouds in heap cloud formations is shown in fig. 1 in which the life history of a cumulo-nimbus cloud is represented in the drawings from left to right.

Fig 1.



The first cumulus cloud to be formed consists only of water drops, it thus represents a super-cooled water cloud in the region above the freezing limit. With the further growth of the cloud, the ascending air stream reaches the temperature at which sublimation on the sublimation nuclei begins and from here onwards ice crystals only are produced; these continue to grow rapidly until they become too large to be supported by the ascending air stream and therefore fall out. When falling through the wide layer in which the super-cooled water drops are present the ice crystals continue to grow rapidly and in this way hailstones are produced. As a result of the continuous inroad of ice crystals the super-cooled water drops are gradually precipitated and the super-cooled water cloud disappears and the ice cloud moves downwards into its place, and hence conclusions can be drawn from the ground with regard to the stratification of ice and water cloud and to the position of the ice accretion zone.

Pure water clouds never produce rain but sometimes drizzle which can only fall to the ground when the cloud is at a low height and the humidity is high. From the absence of rain it can be recognised from the ground that these are purely water clouds in which ice accretion conditions must exist if they lie above the freezing limit. Ice clouds have a much greater tendency to produce precipitation than water clouds. Even alto-stratus does not produce precipitation as long as its base is at a great height as the ice crystals which fall out evaporate in the air. With the continued evaporation the relative humidity rises and the lower limit of the cloud descends, finally the ice crystals reach the super-cooled water regions of the cloud where they rapidly grow into soft hail pellets and fall out and become rain drops.

Water clouds (Ac.) form very regularly at the upper boundary of the ice crystal cloud because the air there is impoverished of sublimation nuclei and with the renewed production of vertical motions only water clouds can be produced. Danger of ice formation consequently nearly always exists in the topmost layer of the rain cloud. In most cases a layer of alto-cumulus is usually only about 200 to 300 metres thick but occasionally it may attain a thickness of 1000 metres or more. This is the case with rain clouds of very advanced age, whose upper limit lies at a low height and which continue to give out only a little rain.

On the basis of observations of precipitation alone it is possible to recognise from the ground the momentary stratification of ice and water clouds. X Observations of the clouds themselves is an additional help, because ice and water clouds exhibit characteristic differences in their outward appearance and it is possible to recognise from the ground or air whether a cloud contains ice crystals or water drops or both and hence whether ice formation may be expected in a cloud or not. X

The old division of clouds according to form and height provides no safe means of distinguishing between ice and water clouds. If new points of view are applied to the known classifications, the clouds that would be classed as ice clouds are cirrus, cirro-stratus, alto-stratus, nimbo-stratus, further as ice and water clouds, cumulo-nimbus and alto-cumulus. In very cold weather wintry strato-cumulus also may occasionally consist entirely of ice crystals, but as a general rule however all other clouds are water clouds, though occasionally ice particles of external origin may also fall through these clouds. The ice clouds are thinner optically and often look like thick haze and their edges are blurred, but the water clouds on the other hand are sharply defined.

In order to judge whether ice formation conditions are to be expected in a cloud or not in addition to the determination of the kind of particles it contains, it is naturally indispensable to know the temperature and for the airman it is sufficient to know the freezing level.

In forecasting the freezing level it is essential to remember that there is a particular freezing level appropriate to every aircraft speed, the level of this being always higher than that of the air, the additional height increasing with the speed of the plane. Owing to these increases in temperature, the freezing level which is the decisive factor for the formation of ice on an aeroplane is always higher than the meteorological freezing level.

The determination of the ice formation zones from the reports from aviation weather service stations and from weather maps must be based primarily on the precipitation and cloud observations of the individual stations, and just as the precipitation and clouds differ at different places so do the ice formation zones.

Uniformity in position and extent of the ice formation zones over large regions does not often occur. Neither are the formation zones connected in any simple manner with fronts or air masses. Frequently in extensive regions of precipitation the danger of ice formation is least, since the quantity of water in super-cooled rain is less than in super-cooled clouds.

SYNOPSIS OF PRESIDENTIAL ADDRESS BY SIR GEO. SIMPSON

April, 1941

The atmosphere always contains large, but varying, amounts of water in one or more of its three physical forms (solid, liquid, or vapour). It is continuously losing water in the form of rain, snow, hail, dew, etc., but this is replenished by evaporation from open expanses of water—seas, lakes, rivers, damp ground. As this increase from evaporation is on the average equivalent to the decrease by precipitation, the average state of the atmosphere remains unchanged.

On leaving the evaporating surface, the water is in the form of an invisible vapour, but, before it can be precipitated, it must be transformed to either the liquid or solid state. It has been shown that this transformation from the vapour state can only take place in the atmosphere when there are nuclei present on which the condensation can take place.

Water molecules will leave a water surface at a rate determined by the temperature. In a closed vessel, these molecules exert a pressure (vapour pressure) on the walls of the vessel, under which pressure a certain number of molecules enter the water surface, the net loss of water being the evaporation.

If there were no nuclei in saturated air, condensation could only take place as the result of water molecules joining together to form drops, and, as the diameter of a water molecule is 4×10^{-8} cm., it would take something like 15,000 molecules to form a drop with a diameter of 10^{-6} cms. It is highly improbable that such a large number of drops would come together by chance, and, even if they did, a super-saturation of 26% would be necessary to prevent evaporation from such a small drop.

The number of molecules leaving the surface of aqueous solution is reduced from that leaving the surface of pure water, so that the saturation vapour pressure over a solution is less. When a solution is exposed to a saturated atmosphere, therefore, it absorbs moisture or is hygroscopic. Similarly, a solid which is soluble in water is hygroscopic, the attraction for water being proportional to the lowering of the vapour pressure by the saturated solution. Hygroscopic nuclei are, therefore, either drops of solution or particles of solids soluble in water.

For a long time, it was held without question that particles which have no natural affinity for water do not act as centres of condensation.

Any reaction between gases or vapours resulting in the formation of a solid or liquid phase will, in the presence of a large excess of indifferent gas, produce a smoke. Smoke particles have diameters mainly between 10^{-6} cms. and 10^{-4} cms.; these smoke particles add to the number of nuclei found in such large numbers in industrial areas. Some of the primary smoke particles, whether liquid or solid, are soluble in water (such as sulphurous and sulphuric acids for sulphur smokes, and nitrous acid from the combination of water, nitrogen, and oxygen from the air in flames) and some are not (such as particles of carbon and drops of tar). The particles which are soluble will, if the relative humidity is sufficiently high, absorb water and form minute drops of solution, and hence become true nuclei. The insoluble particles will act as nuclei, but will not change their size or shape with changes in relative humidity, behaving actually like "dust" particles.

The name "dust" can be applied to insoluble particles in the atmosphere, there being three kinds—(a) solid particles from imperfect combustion, (b) particles of animal and vegetable fibres, and (c) mineral particles formed by the disintegration of the earth's surface. The latter type are in large quantities, especially at temperatures below freezing point.

Spray is the disintegration product of liquids, just as dust is of solids. No known method of spraying can produce a drop with a diameter smaller than 10^{-5} cms., but the majority of drops resulting from spray will be much larger than this. The only spray which provides nuclei in any great numbers in the atmosphere is sea spray.

When air containing nuclei of all kinds and sizes is cooled below the dew point, condensation takes place first on those nuclei with the least supersaturation. The nuclei which are effective in cloud formation are those whose diameters are greater than approximately 2×10^{-5} cms., and those smaller than 10^{-5} cms. take practically no part in the formation. For non-hygroscopic particles to act as effective nuclei, their diameter must not be less than 5×10^{-5} cms., though the number of these nuclei playing an active part will be small compared with the number of hygroscopic nuclei. It appears that nuclei of naturally formed nitrous acid are the chief nuclei on which cloud particles form.

Water can exist in all three phases at temperatures well below freezing point, and liquid cloud particles of this supercooled water nave been found at — 30° C., giving a white rainbow (caused by double reflection within spherical water drops).

Cloud at temperatures below freezing point may be formed in three ways:—

(1) The formation of cloud particles first as water above 0° C., and then changing into ice crystals as the temperature falls below freezing point. Such a process is exhibited by a cumulus or cumulo-nimbus cloud.

(2) The formation of cloud as liquid particles in an atmosphere wholly below freezing point.

(3) The formation of ice crystals by direct sublimation. Such a process is exhibited by cirrus clouds.

The essential difference between a cloud particle and a rain-drop cannot be stated, as "the former floats, and the latter falls," as they both fall, but with different velocities. A water drop diameter 0·01 mm. falls at less than 1 metre/minute, while a drop of diameter 0·5 cm. falls at 8 metres/second. As a water drop falls, it evaporates, and the difference between a cloud particle and a rain drop is that the latter reaches the ground before completely evaporating, while the former will not reach the ground. A cloud particle must grow to 0·2 mm. before it becomes a rain drop.

SECTION 8

See R.A.A.F. Publication No. 153, page 91: Land and Sea Breezes, Katabatic and Anabatic Winds, Foehn Winds.

SECTION 9
TOPOGRAPHICAL EFFECTS

Topography can affect the following:—

1. Temperature of the surface.
2. Lapse rates in the atmosphere.
3. Precipitation.
4. Wind direction and velocity.
5. Cloud formation.
6. Movements of pressure systems.
7. Movement and development of fronts.
8. Properties of an air stream.
9. Visibility.

The effects briefly are:—

1. The slopes facing the sun become heated more than others, because—

   (1) The sun's rays are **more nearly normal to surface;**
   (2) They will usually be exposed for longer periods than oblique surfaces to the sun's rays.

Causes of Local Variation in Temperature

(a) Effect of altitude.
(b) Low radiation temperatures in valleys.
(c) Effect of local clouds on diurnal heating by sunshine or cooling by radiation.
(d) Foehn effect—to lee of high ground.
(e) Differences between land and sea.

2. If air is forced to ascend by topographical features, it will cool at the dry adiabatic lapse rate, unless condensation takes place; above condensation level it will cool at the wet adiabatic lapse rate. Topography will usually change the environment lapse rate, and tend to establish the adiabatic lapse rate. Air descending a topographical feature will warm at the dry adiabatic lapse rate, and is known as a Foehn (or Fohn) wind.

3. When a saturated or nearly saturated air stream meets a range, showers may result if the air is unstable or conditionally unstable, and drizzle if the stream is stable. A coastline is often sufficient to cause a retardation of the surface air with a resulting over-riding and lifting of the following air, and if the air is unstable "coastal" thunderstorms result. There is a tendency for thunderstorms to favour certain regions, the reasons not always being properly understood. Near the coasts, there are differences between temperature conditions over land and sea which often cause instability showers or drizzle.

A "cloudburst" may be caused when a large cumulus cloud has the convection beneath it cut off by passing over elevated ground.

Lee sides are usually dry while windward sides experience frequent precipitation.

4. **Causes of Local Variation in Winds**

(a) Stronger winds off the sea than off the land for the same pressure gradient.

(b) Sheltering effect of high ground to windward.

(c) Tunnel effect through valleys.

(d) Diurnal land and sea breeze.

(e) Variation in turbulence due to ground contour or differences in convection over land and sea.

Topographical features will divert a wind stream, and the ascent of air may form a temperature gradient in the air stream which will introduce a thermal component in the wind.

The surface wind may be changed by anabatic or katabatic winds. An anabatic wind blows up hill slopes; on a fine, warm day due to the heating of the air in contact with the surface, the normal adiabatic cooling is counteracted by contact with the warm surface. A katabatic wind is the downward flow of air near the surface; at night it is actually a gravitational flow of air which is cooled by contact with the cooling surface. These effects are most pronounced on a clear night when the radiational cooling renders the adiabatic warming ineffective. In valleys katabatic winds may develop appreciable velocities.

Eddies will also be caused by topographical features, the size depending on the contours of the ground and nature of the surface, i.e., bare, rugged or covered with vegetation.

5. Various special types of cloud are formed as a result of topographical lifting on air streams. These are discussed in Obs. 11 in detail. In stable air, fog, lenticular, banner or crest clouds may be formed, while in unstable air cumulo-nimbus may form due to the topography giving the necessary "trigger" action. Owing to the increase in lapse rate and turbulence, clouds are usually lower over topographical features than over areas of small relief. Differences in surface conditions will affect the form and height of low cloud. At coastal stations, wind direction affects cloud formation.

6. The movement of pressure systems may be deflected by prominent topographical features by changing the pressure of the upper air due to forced uplift. Pressure systems are sometimes "held up" by high ranges and build up, and when the range is crossed the systems usually accelerate and lose their intensity.

7. Warm fronts are usually retarded, and the duration of precipitation prolonged, and a rain shadow area introduced on the lee side. (See R.A.A.F. Manual 153, page 148.) Cold fronts are retarded, and usually reduced in intensity as they cross the obstruction due to dynamical warming on the lee side, which tends to stabilise the air. (See R.A.A.F. Manual 153, page 151.)

8. Changes in the properties of an air stream must be considered from the individual properties of the air mass, and also the relative directions of the stream and the topographical features.

9. **Visibility** depends upon—

(a) Air stream;

(b) Lapse rates;

(c) Impurities in air, which depend on turbulence, nature of surface, and locality.

The effect of topography on any of these will affect the visibility.

Causes of Local Variation in Visibility

(a) Valley fogs.

(b) Hill fogs (low cloud on hills).

(c) Differences between land and sea.

(d) Smoke effects (according to wind direction).

(e) Effect of local clouds and local winds on the formation of radiation fog.

(f) Effect of the nature of the ground on radiation fog.

The above treatment is only a guide, and further information may be obtained from the R.A.A.F. Manual 153, the Admiralty Weather Manual, and similar references.

SECTION 10

DENSITY ALTITUDE

For aviation purposes there are two standard atmospheres—one (the isothermal atmosphere) is being displaced by the other (the I.C.A.N. atmosphere). In the latter every air density corresponds to some altitude and the density at any given altitude may be expressed as an equivalent "standard" atmosphere or "density altitude" which may vary considerably from the actual altitude.

The density altitude is the altitude on the I.C.A.N. pressure scale at which the air density would be the same as the air density actually prevailing at the time.

The significance of the density altitude to a pilot is that the performance of the aeroplane at the known height of flight or take-off would be the performance at the height given by the density altitude in the standard atmosphere, e.g., if an aeroplane were taking-off at an aerodrome of altitude 2,000 feet and the density altitude was 5,000 feet the length of runway necessary would be the same as an aerodrome at 5,000 feet with standard conditions of pressure and temperature. In this way also performance of aircraft may be compared.

The density altitude depends on the temperature, humidity, and air pressure. A series of curves has been prepared which enables the density altitudes to be readily obtained for any station.

The I.C.A.N. atmosphere assumes a mean sea level pressure of 29·92 inches and temperature of 15° C. and perfectly dry air with a lapse rate of 1·98° C. per 1,000 feet. The standard mean sea level density is 1·225 grams per cubic metre.

The effect of humidity is to decrease the air density, since water vapour is only 0·622 times as dense as air. Allowance is made for this by using a "virtual" temperature which is the temperature of dry air which would have the same density as the moist air at the same pressure.

The virtual temperature is found from a graph in the lower left-hand corner of the Density Altitude Chart and will **always** be **added** to the dry bulb temperature.

To find the density altitude for a station—

1. Read barometer and correct to **STATION LEVEL** to nearest tenth of an inch (say, 27·6 inches);
2. Read screen dry bulb temperature to nearest degree Fahrenheit (say 87° F.) and also the wet bulb temperature (say 76° F.);
3. Determine the relative humidity to the nearest 10%, e.g., 60%;

4. Determine the virtual temperature to the nearest degree using the humidity correction graph (6° F.) and add this to the dry bulb temperature ($87 + 6 = 93°$ F.);

5. Look along base of Density Altitude Diagram until the station level pressure is found (each vertical line is 0·2 inch);

6. Look vertically above this point until the virtual temperature line is met;

7. Look horizontally and find what density altitude corresponds to this point of intersection, to the nearest 500 feet (5,000 feet);

any negative value being expressed as zero.

Notice that humidities of under 20% are negligible and below 70° F., even 40% humidity may be neglected.

It is interesting to note that a pressure of 27·6 inches corresponds with an isothermal height of approximately 2,300 feet, and even when corrected for temperature departure gives only 2,425 feet assuming an isothermal lapse rate.

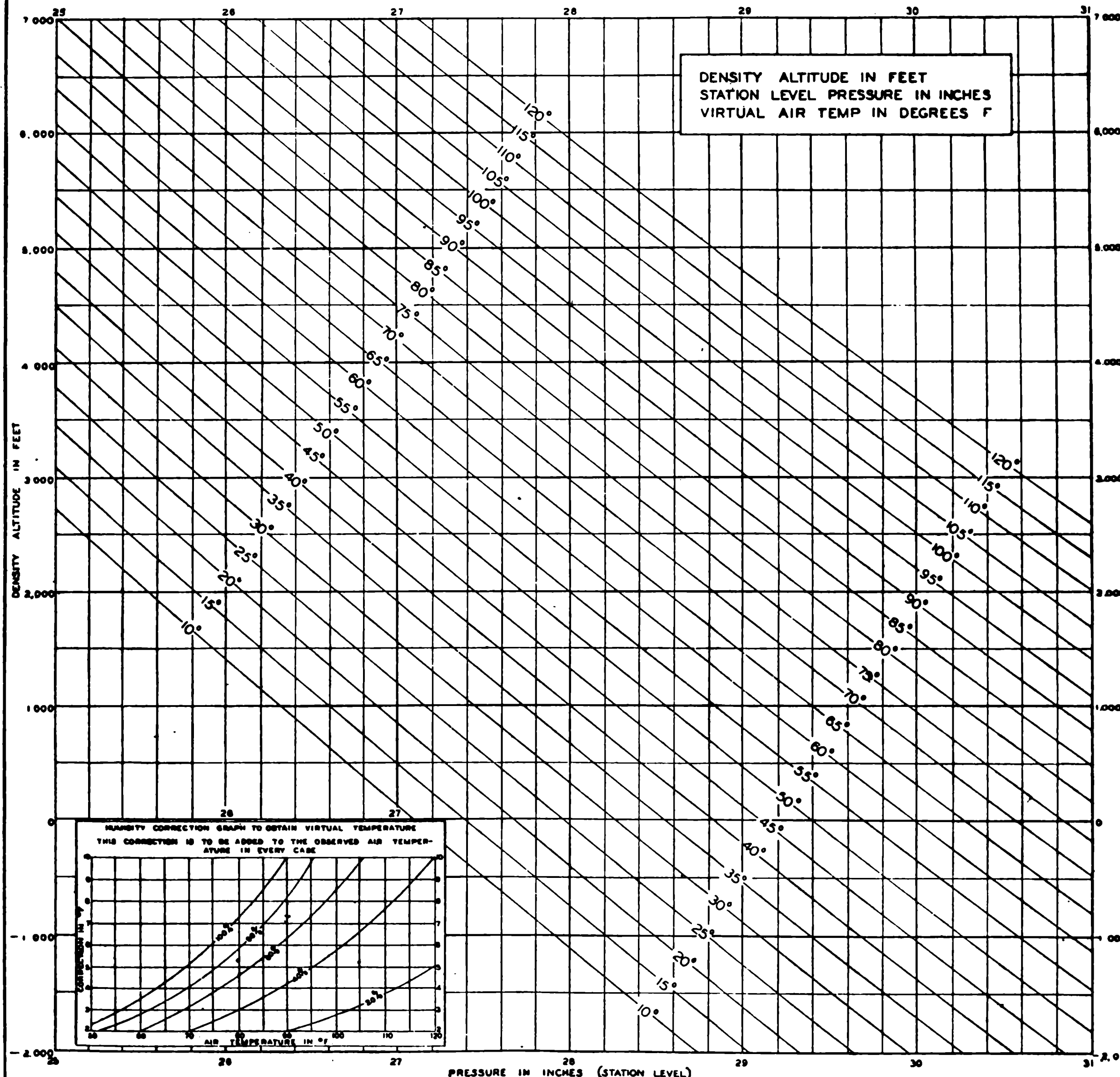
Density altitude advice is issued subject to instructions of the Aviation Department.

F. 124

DEPARTMENT OF AIR

COMMONWEALTH METEOROLOGY

DENSITY ALTITUDE DIAGRAM



SECTION 11

METEOROLOGICAL ASPECTS OF CHEMICAL WARFARE

GENERAL.

Gases used in warfare are usually liquids or powders—true gases are too difficult to maintain in sufficient concentration. The chemicals may be persistent, i.e., potent or effective over a considerable period of time, or non-persistent, i.e., effective for only a short period of time.

The following are the main types of gases used and the common examples of each type:—

1. Lung Gases ..	Chlorine - true gas - non-persistent. Phosgene - liquid, boiling point 8° C., non-persistent - delayed action.
2. Paralysant Gases	Not successful - not used - hydrocyanic acid best example.
3. Tear Gases ..	Mainly bromides - effective in very low dilutions in order of 1 in 1,000,000. Often mixed with lung gas.
4 Dual Purpose ..	(Tear and Lung.) Main one used Chloropicrin, a liquid boiling at 112° C. - very persistent and stable - resists action of most acids and alkalies, not soluble in water and not absorbed by some types of charcoal. Others used: Diphosgene (Trichlormethylchloroformate) and Brominated ethyl methylketone.
5. Blister Gas ..	Mustard Gas (Dichlorethyl sulphide), a liquid boiling at 217° C., freezes at 10° C. - very persistent and stable. Lewisite - an arsenic derivative - more drastic than mustard gas but not as stable - is hydrolised by water.
6. Nose or Nerve Chemicals ..	Toxic smokes - are all powders and arsenic derivatives. Effective with concentrations as low as 1 in 25,000,000. Not absorbed by charcoal but by cellulose wool. May have various effects from causing sneezing to neuralgia.

METHOD OF PROJECTION

From generators, by shells, bombs or by spray from aircraft.

Generators usually used for close work and smoke screens, also for tear gases. Bombs and shells usually have a small explosive charge to scatter the gas which is usually of lung or blister type.

Spraying from aircraft is done by a propellant from a jet so that the gas has a rearward velocity the same as the aeroplane, so that the resultant air speed is zero.

METEOROLOGICAL ELEMENTS CONCERNED

1. **Wind** can distribute or disperse the gas depending on the velocity. The persistence depends on the rate of evaporation, i.e., on wind velocity (and also temperature). Gas from a shell or bomb drifts with the wind in a sector with an angle of approximately 20° on each side of the wind direction. In calm conditions the gas drifts in a circle centred at the point of release. As the effective depth of a gas layer is 20 to 25 feet vertical currents will tend to increase this and thus lessen the effect.

2. **Temperature** affects mainly the persistent gases. Both soil and air temperature need to be known.

3. **Lapse Rates** affect vertical currents in the atmosphere and thus the depth of gas layer. The most suitable lapse rates are an inversion, an isothermal layer or a layer with a very small lapse rate.

4. **Rain.**—Light rain tends to keep the gas low and may increase its effect unless the gas is decomposed by water. Heavy rain may beat the gas down to an ineffective height and may wash gases off a non-absorbent surface.

5. **Topography.**—Not actually meteorological but important. Low lying areas, valleys, etc., will form pockets whereas hillsides and high areas should be fairly free from persistent contamination.

NOTE: Meteorological situations suitable for a gas attack are similar to those for fog.

METEOROLOGICAL CONDITIONS FOR VARIOUS GASES

1. **Smoke Screens and Toxic Smokes**

Temperature has no effect.

Wind Speed: For generator, 8 m.p.h.; for shells, 15 m.p.h.

Little or no vertical currents, i.e., stable atmosphere and overcast conditions.

2. **Non-persistent Clouds**

Wind speed, 5-18 m.p.h.

Moderate temperatures. High temperatures cause rapid evaporation and vertical currents, i.e., inversion favourable. In summer the lapse rate from 1-10 metres above surface may be 3° F., i.e., 18 times D.A.L.R.; the usual lapse rate for overcast conditions is 1·3° F. for the same range. Knowledge of wind speed at 1 and 2 metres is required (this necessitates a special anemometer), also of lapse rates in the lower atmosphere.

Ideal conditions: Clear nights, wind velocity 5-18 m.p.h. and

$$\frac{\text{velocity at 2 m.}}{\text{velocity at 1 m.}} = 1{\cdot}35.$$

If this ratio is less than 1·05 conditions are unsuitable for non-persistent clouds.

3. **Persistent Gases**

Surface temperature most important factor. Sufficient mustard gas to give 14 days' effect in winter would last for 6 hours on a hot summer day. The evaporation of mustard gas is one-twentieth of that of water at 60° F. and at 140° F. is 50 times that at 32° F.

The rate of evaporation is proportional to wind velocity, i.e., time of persistence is inversely proportional to wind velocity.

Effect of surface—absorbent surfaces: wood, soil, tar, snow, clothing—increase persistence, but non-absorbent surfaces such as metals do not aid persistence, but may increase activity due to having usually a higher temperature.

Rain.—Light rain usually keeps the gas low and increases the persistence unless the gas is affected by water. Heavy rain usually reduces the efficiency of a gas and may wash it away.

Conditions Favourable for Persistence

1. Low air and soil temperature.
2. Low wind velocity.
3. Absorbent surface.
4. High contamination.

Conditions Favourable for High Concentration.

1. Sufficiently high soil and air temperature to ensure evaporation of the gas into the air but a relatively stable lapse rate so that the gas will be maintained in a layer through a depth of 20-30 feet.
2. A wind velocity that will ensure sufficient turbulence to distribute the gas through the required depth.
3. Non-absorbent soil or surface.
4. Gas concentrated over a small area.

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July, 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course for Meteorological Assistants

PART 4

Aeronautical Meteorology

FOR OFFICIAL USE ONLY.

R.A.A.F. Publication No. 248
(July 1942.)

ROYAL AUSTRALIAN AIR FORCE

Instructional Course for Meteorological Assistants

PART 4

Aeronautical Meteorology

AERONAUTICAL METEOROLOGY

CONTENTS

Section 11. **Dust Storms—**
Section XX, p. 125* .. .. ..

Section 12. **Ice Accretion on Aircraft—**
Types of ice accretion, formation of ice in clear air, cloud and rain - effects of topography - conditions associated with risk of ice accretion in Australia - avoidance of icing - de-icing and anti-icing methods. Section XIII, pp. 95-100* .. ..

Section 13. **Thunderstorms—**
The thunderstorm cloud - hailstones - essential conditions for formation of thunderstorms - situations favouring thunderstorms, kinds of thunderstorms - seasonal incidence - dangers to aircraft. Section XIV, pp. 103-106*

Section 14. **Lightning and Aircraft—**
Occurrence of strong electric fields; necessity for adequate metallic bonding; effect of trailing aerial; static charges on aircraft; possible damage caused by lightning; subsequent magnetic effects on compass. Section XV, pp. 107-110* .. ..

Section 15. **Line Squalls—**
Meaning of line squalls - risks to aircraft - "morning glories" - "southerly bursters" - thunderstorm squalls - the mechanism producing a line squall - conditions for thunder. Section XVI, pp. 110-114* .. .. ..

Section 16. **Air Masses—**
Definition of an air mass; factors affecting properties of an air mass; classification of air masses — properties of a cold air mass, properties of a warm air mass. Section XXIII, pp. 140-143* .. ..

Section 17. **The "Polar Front" Theory of Extra-tropical Depressions—**
The nature of the boundary between two air masses; the development of an extra-tropical depression. "Stationary," "Warm" and "Cold" fronts; occlusions. Section XXIV, pp. 143-145* .. ..
Frontal Zones in Australia. .Section XXIV, pp. 153-155*

Section 18. **Tropical Cyclones—**
Hurricane regions - origin of tropical cyclones - characteristics of tropical cyclones - aviation aspects of tropical cyclones. Section XVIII, pp. 118-121* .. ..

*See References, "R.A.A.F. Manual of Meteorology," No. 153.

SECTION 1

AERONAUTICAL METEOROLOGY

GEOGRAPHICAL ASPECTS OF AUSTRALIA

A. TOPOGRAPHICAL

1. POSITION

Australia lies wholly between parallels 10° S. and 45° S. and meridians 110° E. and 155° E. Two-fifths of its area lies north of the Tropic of Capricorn, the remainder (except Tasmania) between the tropic and 40° S. Thus Australia is largely a tropical and subtropical country.

2. ENVIRONMENT

The continent is isolated from other large land masses by broad stretches of ocean, the Pacific on the east, the Indian on the west. Scattered throughout the Pacific, however, are myriads of islands, especially between the Equator and southern tropic. The islands to the N.E. of Australia occur as festoons or great arc-like formations. One great arc extends from New Guinea, through the New Britain and New Ireland, the Solomons, New Hebrides to New Caledonia and Norfolk Islands. To the N.W. another arc extends from New Guinea to Amboina, Timor, Java and Sumatra.

3. TOPOGRAPHY

Australia is a large but compact land mass of about 3,000,000 sq. miles—about 2,400 miles from west to east and a little less than 2,000 miles in greatest length from north to south.

Australia is in the main a plateau continent. Most of it is over 500 feet above sea level, yet the highest peak, Mt. Kosciusko, reaches only 7,318 feet. The surface may be regarded as falling into well defined divisions:—

(a) The Eastern Highlands.

(b) The Central Highlands.

(c) The Great Western Plateau—extending over nearly half the total area of the continent.

(d) The Central Lowlands, the surface of which is composed largely of the sediments carried down by the erosion of the highland areas and deposited in an ancient sea bed.

(e) Coastal Plains.

(a) **The Eastern Highlands**

These extend in a long bow parallel to the coast from Cape York Peninsula to Tasmania. They are best described, not as mountain ranges, but as a series of much dissected plateaux. The greatest heights are in the S.E. corner. The eastern edges are, in most cases, steep scarps. To the west of the escarpment the plateaux have a more even surface, and slope back gently to the central plains.

In Queensland the highlands are on the whole lower and broader than they are to the south. However, the Atherton Plateau, to the west of Cairns and Townsville, is above 2,000 feet, and rises to 5,500 feet at Mt. Bartle Frere in the Bellenden Ker Range, the coastal range of the plateau. Further south the ranges recede further from the coast; for instance, the divide behind Rockhampton is 300 miles from the sea.

In New South Wales the highlands are closer to the coast than in Queensland—the main divide curving towards the ocean from the Buckland tablelands—300 miles inland from Maryborough to within 20 miles of the coast in the New England Plateau enclosing the Darling Downs. Three divisions are recognisable—the New England Plateau, the Blue Mountains and the Kosciusko Plateau. The New England Plateau, the northern block, averages about 3,000 feet and rises to 5,000 feet at Ben Lomond. On the southern side of this plateau and west of Newcastle is the Hunter River Valley, at the back of which is the pass that forms one of the most important gateways to the Pacific, the Cassilis Gate.

South of this section the highlands occur as a series of massive blocks of which the Blue Mountains and the Kosciusko Plateau are the most noteable. The Blue Mountain Plateau falls away sharply on the seaward face, and is dissected by the coastal rivers into a series of remarkable canyons and gorges. Between this and the S.E. knob, at an elevation of 2,000 feet, occurs the important L. George Gap, through which the main route to the S.W. taken by the Sydney-Melbourne railway passes. South of this gateway are three blocks separated by deep gorges and culminating in summits that are the highest in Australia—Kosciusko (7,138 feet), Bogong, Feathertop and Hotham (all over 6,000 feet).

Connecting the gorges of the Tambo and Mitta Rivers is the Omeo Gap at an elevation of 3,000 feet. West of the Southern Alps the highlands diminish in mass and fall away to the Kilmore Gap (1,200 feet) north of Melbourne, the main gateway from the south. Westward again the ranges rise to a height of 2,000 feet in the summits of the Pyrenees and the Grampians. Towards Cape Otway and Wilson's Promontory there are other highland regions.

The Tasmanian highlands present a plateau rising toward the centre of the island to Cradle Mount (5,000 feet) and towards the N.E. to Ben Lomond (5,000 feet).

The following is a list of stations and their numbers and heights above sea level located in the Eastern Highlands:—

No.	Station	Altitude Feet	No.	Station	Altitude Feet
200	Coen	2000	297	Cowra	978
209	Georgetown	990	307	Wagga	612
211	Mount Surprise .	1487	308	Cootamundra . . .	1082
222	Camooweal	738	313	Armidale	3333
229	Richmond	700	314	Tamworth	1240
231	Hughenden	1074	323	Bathurst	2206
232	Clermont	870	324	Katoomba	3349
233	Winton	606	330	Goulburn	2096
235	Longreach	612	331	Canberra	1837
237	Herberton	2890	333	Kiandra	4578
238	Charters Towers .	1019	334	Mount Kosciusko .	5018
245	Blackall	929	750	Bowral	2171
246	Emerald	588	782	Mount Victoria . .	3390
259	Adavale	750	814	Glen Innis	3520
261	Tambo	1293	806	Orange	2846
263	Charleville	965	803	Murrurundi	1548
266	Cunnamulla . . .	629	346	Ararat	1028
267	Miles	993	354	Beechworth	1810
268	Mitchell	1104	355	Hotham Heights .	6100
269	Roma	1010	356	Omeo	2108
270	Bollon	600	364	Ballarat	1435
271	Goondiwindi . . .	720	824	Kyneton	1677
273	Stanthorpe	2656	830	Mount Buffalo . .	4370
274	Dalby	1131			
284	Inverell	1980			
286	Cobar	822		**Tasmania**	
289	Tenterfield	2830			
290	Coonabarabran . .	1673	392	Oatlands	1418
292	Dubbo	870	395	The Springs	2403
294	Mudgee	1635	841	Waratah	2047
295	Parkes	1035	842	Miena	3325
296	Forbes	781			

(b) **The Central Highlands**

This is an irregular belt of broken highlands extending from the Kimberley Ranges through the Macdonnell and Musgrave Ranges in Central Australia to the Flinders and Mount Lofty Ranges.

The following is a list of stations, station numbers and altitudes located in the Central Highlands:—

No.	Station	Altitude Feet	No.	Station	Altitude Feet
006	Hall's Creek . . .	1225	162	Kapunda	803
114	Alice Springs . . .	1901	170	Sterling West . . .	1628
117	Charlotte Waters.	645	171	Mount Barker. . .	1083
150	Yongala	150	174	Clare	1300
			282	Broken Hill	1000

(c) The Great Western Plateau

This great plateau is an ancient peneplain, average height about 1,000 feet, rising about 3,000 feet in the N.W. It occupies about half the area of the continent. As a result of the extreme dryness of the climate over most of the plateau the general surface is unusually level. Wind erosion is very active and the loose soil has filled up the depressions and smoothed out the surface of the country. The plateau joins up with plateaux in Queensland by the Barkly Tablelands.

The following is a list of stations, station numbers and altitudes in the Great Western Plateau:—

No.	Station	Altitude Feet	No.	Station	Altitude Feet
022	Marble Bar	595	082	Laverton	1530
023	Nullagine	1265	084	Menzies	1404
039	Mundiwindi	1840	086	Southern Cross . .	1170
042	Meekatharra . . .	1700	087	Kalgoorlie	1247
044	Cue	1488	088	Coolgardie.	1389
046	Yalgoo	1044	093	Rawlinna	607
047	Murgoo	1100	715	Merredin	1046
051	Watheroo	805	718	Narrogin	1114
059	York	572	107	Daly Waters . . .	691
060	Kellerberrin	820	112	Tennants Creek .	1075
064	Wandering	1100			
066	Katanning.	1016		**Barkly Tableland**	
074	Collie	604			
076	Willuna	1700	225	Cloncurry	633
080	Lawlers	1580	222	Camooweal	738

(d) The Central Lowlands

The central depression between the Eastern and Central Highlands is one of the largest expanses of true plain country that exist. It comprises a series of shallow drainage basins stretching from the Gulf of Carpentaria to the Southern Ocean, and from the Darling Downs to the west of Lake Eyre. Part of the area drains north into the shallow Gulf of Carpentaria, but the major portion belongs to the inland drainage system of Lake Eyre. Both now form the Great Artesian Basin from the presence of subterranean water upon which the region is so dependent. A second great basin lies in the south-eastern curve of the Great Divide, and drains away through the wide deltaic flood plain of the Murray-Darling Rivers. It is known as the Murray-Darling Basin.

The following is a list of stations, station numbers and altitudes in the Central Lowlands:—

No.	Station	Altitude Feet	No.	Station	Altitude Feet
124	William Creek	250	342	Nhill	481
128	Farina	304	343	Swan Hill	230
130	Tarcoola	395	348	Echuca	318
283	Wilcannia	267	349	Benalla	559
285	Bourke	361	351	Bendigo	731
286	Cobar	822	353	Seymour	464
288	Walgett	436	358	Hamilton	615
298	Wentworth	125	821	Boort	306
300	Moree	686	161	Berri	215
302	Hay	310	203	Normanton	31
304	Deniliquin	311	204	Karumba	50
306	Leeton	406	205	Burketown	30
310	Albury	534	223	Urandangie	550
785	Mungindi	528	227	Boulia	478
813	Corowa	503	258	Windorah	390
340	Mildura	177	265	Thargomindah	402
341	Horsham	454			

(e) **Coastal Plains**

These are shown on the map along the western and eastern coasts.

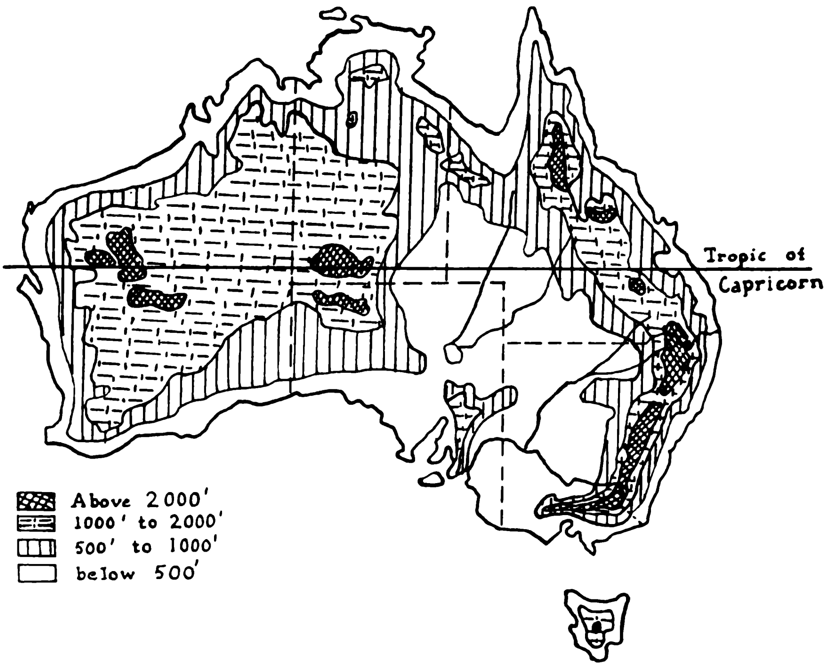
The Great Barrier Reef lies off the east coast of Queensland at a distance of 30 to 70 miles. It stretches for 1200 miles from the tropic to New Guinea.

The following is a list of station numbers and altitudes of stations located along the Coastal Plain:—

No.	Station	Altitude Feet	No.	Station	Altitude Feet
	Western Australia			**Nullarbor Plain**	
003	Wyndham	23			
009	Derby	53	072	Esperance	14
011	Broome	63	099	Eucla	15
018	Pt. Hedland	25	134	Cook	404
020	Roeburn	40	138	Fowler's Bay	15
027	Onslow	14	139	Ceduna	40
031	Winning Pool	280	140	Streaky Bay	43
033	Carnavon	15			
035	Hamelin Pool	14		**South Australia**	
049	Geraldton	13			
054	Rotnest Island	155	145	Port Lincoln	13
055	Fremantle	119	148	Port Augusta	18
057	Perth	197	154	Port Pirie	16
058	Pearce	200	156	Snowtown	339
061	Bunbury	17	158	Kingscote	50
062	Cape Naturaliste	365	159	Cape de Couedie	488
063	Busselton	9	168	Adelaide	140
065	Cape Leeuwin	163	175	Robe	20
068	Albany	41	177	Mount Gambier	138
069	Eclipse Island	387	178	Cape Northumberland	124

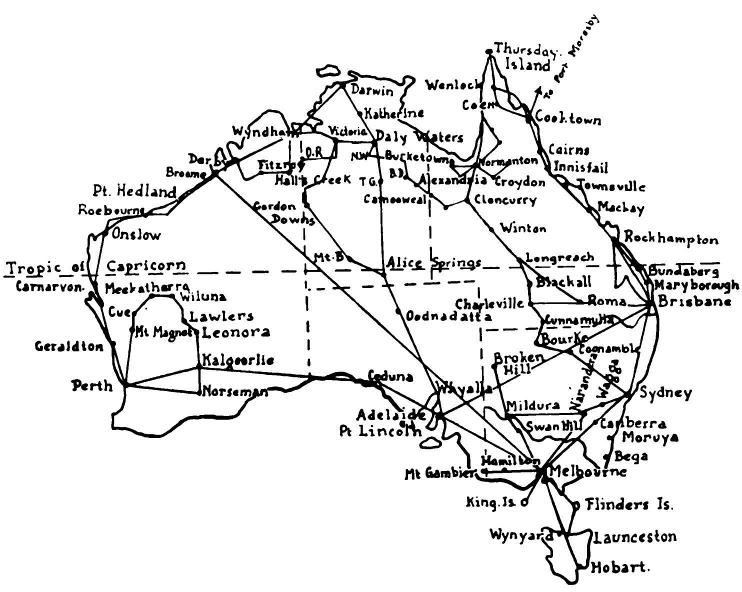
No.	Station	Altitude Feet	No.	Statian	Altitude Feet
	Northern Territory		322	Rathmines	—
			326	Sydney	138
102	Darwin	97	328	Wollongong	33
105	Groote Eylandt . .	—	336	Jervis Bay	257
			338	Moruya Heads . .	55
			339	Nowra	50
	Queensland		280	Bega	50
201	Thursday Island . .	17			
212	Cooktown	17		**Victoria**	
213	Port Douglas . . .	12			
215	Cairns	16	359	Portland	51
216	Willis Island . . .	—	360	Warrnambool . . .	90
218	Cardwell	21	361	Cape Otway	270
219	Townsville	73	365	Laverton	—
221	Innisfail	22	367	Melbourne	115
240	Bowen	16	360	Geelong	90
242	Mackay	35	369	Queenscliffe . . .	90
244	St. Lawrence . . .	45	373	Wilson's Prom. . .	373
247	Rockhampton . . .	37	375	Sale	31
251	Bundaberg	45	377	Bairnsdale	49
252	Maryborough . . .	27	379	Gabo Island	50
253	Gayndah	342			
255	Sandy Cape	330			
276	Cape Morton . . .	331		**Tasmania**	
278	Brisbane	137			
			381	King Island	64
			382	Stanley	37
	New South Wales		384	Cape Sorrell	73
			386	Low Head	92
312	Lismore	37	387	Launceston	266
315	Clarence Heads . .	99	389	Eddystone Pt. . . .	44
317	Smokey Cape . . .	100	391	Swansea	25
318	Kempsey	31	394	Hobart	177
319	Port Macquarie . .	44	397	Cape Bruni	188
321	Newcastle	112	388	Flinders Island . .	—

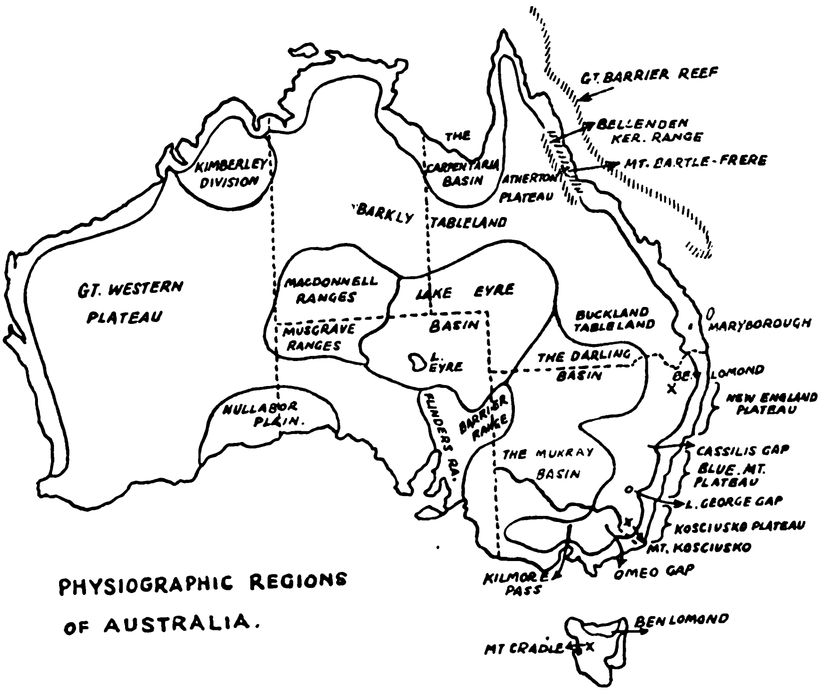
New Guinea possesses every variety of surface, from low lying swampy and densely forested plains drained by a network of rivers, to towering summits 15,000 feet above sea level. A complex mountain system runs right through the island occupying, in the main, the northern half and northward and southward peninsulas. The main divide is known variously as the Nassau Mountains in Dutch New Guinea, and as the Victor Emanual, Bismarck and Owen Stanley Ranges in the British territory. The greatest heights are reached in the Nassau Mountains, but the mountains, Blucher, Scratchley and Victoria, are all over 13,000 feet.



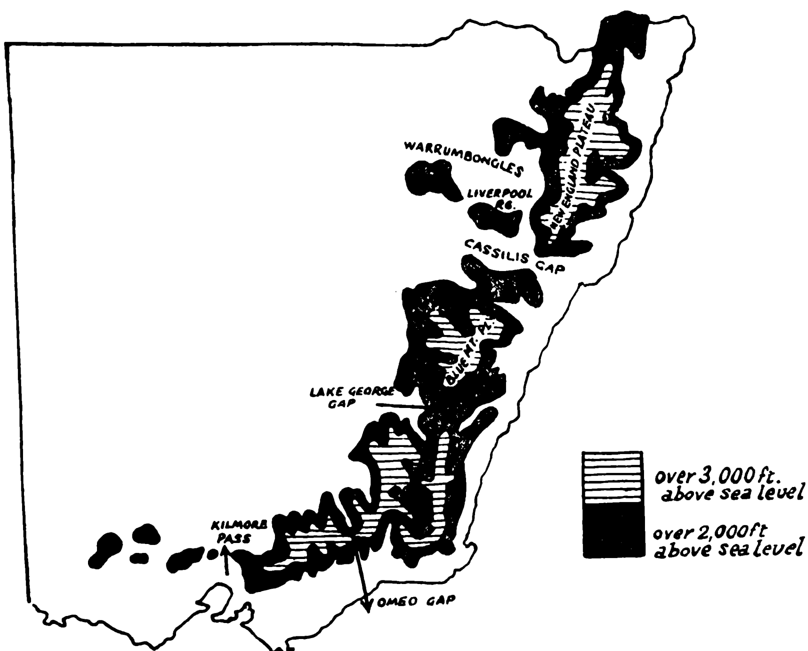
4. MAIN AIR ROUTES OF AUSTRALIA

The main air routes are shown in the diagram below.





PHYSIOGRAPHIC REGIONS OF AUSTRALIA.



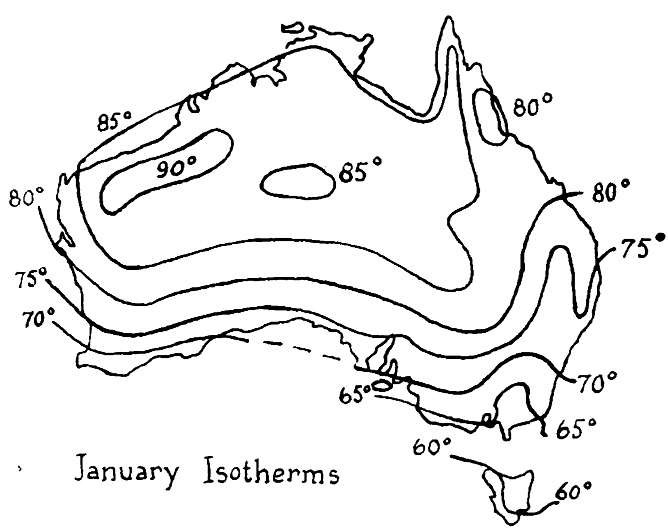
CONTOURS - SOUTH EASTERN AUSTRALIA.

B. CONTROLLING FACTORS OF CLIMATE IN THE AUSTRALIAN REGION

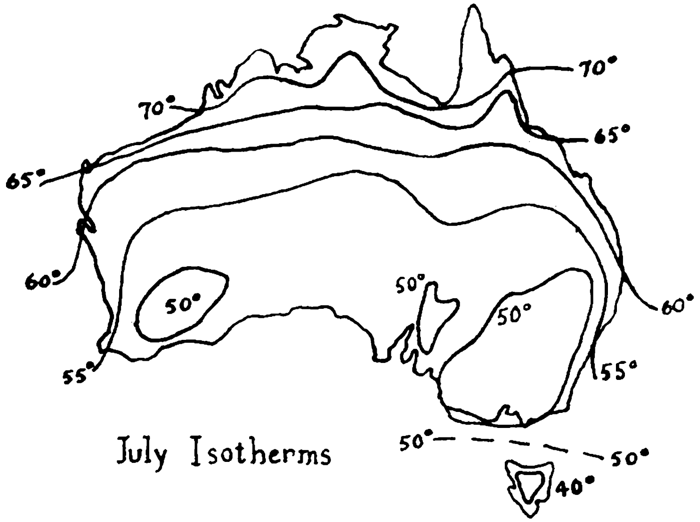
About two-fifths of the area of Australia lies north of the Tropic of Capricorn, so that these lands have a tropical climate, maritime or continental according as distance from the coast increases. The rest of the continent has a subtropical or warm temperate climate, and again parts of these areas are affected by continentality, and show big ranges between extremes of temperature. It should be borne in mind that the continent lies within those latitudes where the chief warm deserts of the world are to be found, i.e., between the regions of equatorial and monsoon rains, and the regions of temperate and cyclonic rains. In fact, most of subtropical Australia lies in the track of anticyclones, which are large areas of subsiding air, thus operating against the formation of rain other than light showers or drizzle. Further, the greatest extent of the continent is along the parallels of latitude, and the mountains which may act as obstructions in the paths of air masses are few and not high. The effect is to present a large proportion of the surface to desert forming influences.

1. TEMPERATURE

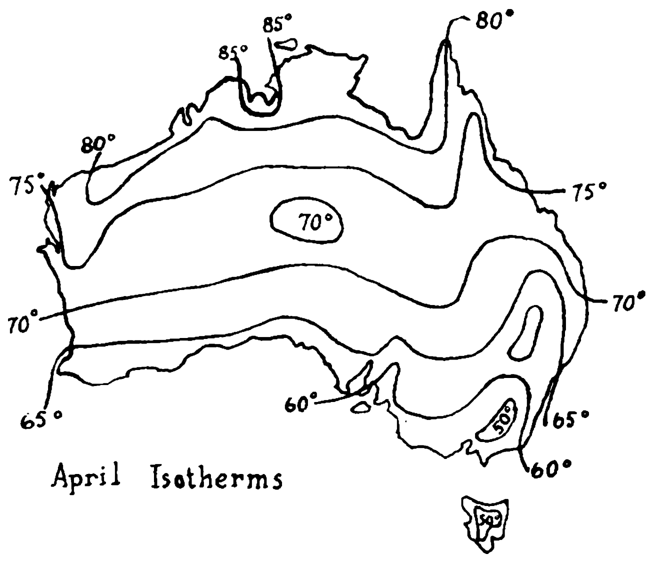
The isotherms for January and July show the temperature conditions for the warmest and coldest months respectively, while those for April and October show the temperature conditions at the intermediate seasons.



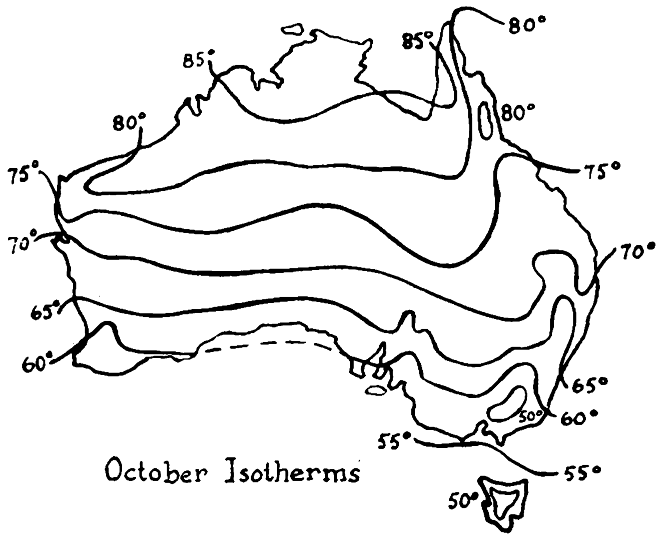
January Isotherms



July Isotherms



April Isotherms



October Isotherms

In midsummer, all tropical Australia and a large part of adjacent temperate Australia have an average temperature over 80° F. The region of greatest heat is not the most northern part, but the inland central and north-west areas, particularly the Pilbara district in which Marble Bar and Nullagine are situated. In this N.W. portion of Western Australia at Marble Bar, the maximum temperatures have exceeded 100° F. on 161 consecutive days. While the regions mentioned register the highest temperatures in the summer period, throughout the year the region of greatest heat is around Wyndham, where excessive heat and high humidity make climate the most uncomfortable in Australia. Latitude for latitude, the interior is warmer than the coastal regions, while the east coast in the tropical region is generally cooler than the west, though the wet bulb temperatures are higher. High temperatures occur everywhere in the interior near the tropic, where the cloudless sky and drier air give free passage to the sun's rays. Alice Springs, situated practically on the tropic, 2,000 feet above the sea, records 115° in most years. Intense heat is sometimes experienced far south, even on the south coast, e.g., Bourke has recorded 121°, Adelaide 118°, Sydney 114° and Melbourne 114°. The heavy rain, thick clouds, and high humidity of the summer monsoon preclude such high temperatures in the north as are experienced in parts of the continent with a higher latitude. The warmest month at Darwin is November, with a mean temperature of 84°; the highest temperature in most years does not exceed 100°. The isotherms have a general east-west direction, but tend to run parallel to the south coast, bending northwards as they approach the east coast. There is a similar, but much smaller bend towards the north, in the neighbourhood of the west coast.

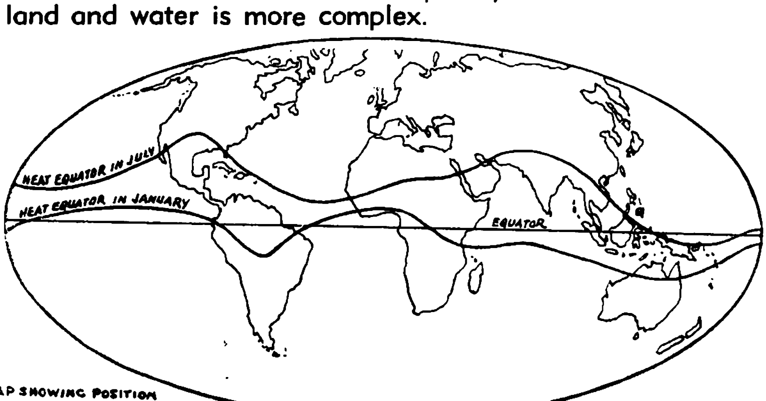
In April, there is a marked drop in temperature everywhere; the 85° F. isotherm encloses N.W. Australia, and the 55° F. isotherm appears over Victoria.

In midwinter the sun is no longer overhead in Northern Australia, and the average temperatures drop to about 60° F. The isotherms advance equatorwards. The 75° isotherm moves about 1,200 miles north as winter approaches from January to July, the cooling being quickest in April and May. The N.W. coast is the warmest part of the continent, which has a mean temperature just over 75°. South of the tropic the temperatures are much lower, and may fall below freezing point on winter nights. In the arid interior, even the summer nights are occasionally cold, and, in most winters, the temperature falls as low as 25° at Alice Springs. On the south coast, although the mean temperature is lower, the nights are less cold owing to the influence of the sea—at Adelaide the temperature has fallen to freezing point, and at Melbourne to 27°. In the south, the coolest regions are the S.W. corner, Victoria, and southern New South Wales, in each of which the average figure is below 50°. F. The Australian Alps, situated in north-easternVictoria and south- eastern New South Wales, form the coldest portion of Australia, the mean temperature range being from 65° F. in January to 40° F. in July—Kiandra, 4,640 ft. above M.S.L., has recorded — 8° F. In this highland region snow falls mainly during the period May to September.

The distribution of temperature during the month of October is similar to that of April, except that the isotherms conform more closely to the parallels of latitude.

The Thermal Equator

The thermal or heat equator is in the Northern Hemisphere in July, and in the Southern Hemisphere in January, when it crosses northern Australia. Its average position is mostly north of the geographical equator. Generally speaking, temperature decreases north and south of the heat equator more regularly over the oceans than over the land, and more regularly in the Southern Hemisphere than in the Northern Hemisphere, where the distribution of land and water is more complex.



MAP SHOWING POSITION of THERMAL EQUATOR

Certain points are observable in the distribution of temperature over Australia:—

(a) **Latitudinal Temperature Gradient:**

There is a general decrease in temperature from the equator towards the poles. The average rate of decrease of temperature with increase of latitude is much greater in winter than in summer, so that any phenomenon which depends on the variation of temperature in the horizontal will be more intense in winter than in summer.

(b) **Seasonal Range**

Most of Australia has a relatively small seasonal range of temperature, the range being particularly small in the tropics; Darwin, for instance, has a range of temperature between summer and winter of only 8·4° F. Places with coastal location have a smaller range than have places in the interior. The interior has comparatively hot summers and cold winters.

(c) **Diurnal Changes**

In addition to seasonal changes of temperature, there are important diurnal changes. The influence of the sea results in coastal locations having relatively small variations of temperature from day to night, while continental regions have a larger diurnal range of temperature. In the interior, this difference is accentuated because the small amount of cloud and the low humidity allow great absorption of heat by day and a great amount of radiation of heat after sunset. The night temperatures often drop almost to freezing point, although during the day they may have been between 90° to 100° F.

The diurnal variation also increases with decreasing latitude because of the greater insolational heating during the day in the lower latitudes. The amplitude of the diurnal variation not only differs for different localities, but also differs for different times of the year, being much greater on the average in summer than in winter. The actual diurnal range observed within any selected interval of 24 hours will depend, however, largely on the weather at the time. A clear sunny day, followed by a clear, calm night, will yield a range of temperature far in excess of the average, while a cloudy day, followed by a cloudy night, may give no appreciable variation of temperature during the whole interval.

(d) **Interruptions to the Latitudinal Temperature Gradient**

(i) **Northerly Streams:** Although, generally speaking, temperature decreases with increase of latitude, sometimes the presence of unstable northerly streams in summer time yields quite a number of days, particularly during the months of December, January and February, when the surface air temperatures during the day, actually show an increase of temperature with latitude. The temperature has been known to rise to 120° in the north of Victoria, and South Australia, while Melbourne has recorded

maximum temperatures of over 100° on six consecutive days, when the pressure distribution has been such as to cause a steady flow of air from the north.

Because of the heating of the land surface during summer, northerly streams are heated from below, and so made unstable. As they travel southwards, they bring to places of higher latitude temperatures higher than those which would otherwise be experienced.

In winter time, on the other hand, the air is cooled by contact with the land, and, owing to the excessive amount of heat lost by outgoing radiation during the long winter nights over the drier land surface away from the coast, northerly streams may bring abnormally low temperatures to southern Australia. However, winter northerly streams bring abnormally low temperatures to more restricted areas than the areas heated in summer by winds from the same direction.

(ii) **The Effect of Topography in Relation to Winds:** Air flowing down mountain slopes is warmed adiabatically, and will often account for higher temperatures on the slopes and low lying areas. The "Chinook" winds (westerlies) keep the eastern foothills of the Rockies relatively free of ice and snow in winter time, while easterly winds account for high temperatures in summer at places on the western slopes of the Great Dividing Range, and westerly and north-westerly winds yield abnormally high temperatures along the eastern slopes and coastal stretches along the Eastern Highlands.

As regards Australia as a whole, the temperature extremes—annual, seasonal and diurnal—are less than those experienced in the other continents of the world. While the climate may be generally described as warm to hot, the mean temperatures prevailing are generally lower than for corresponding latitudes, in the other land areas. These features are due mainly to the insularity of the continent of Australia, the lack of high elevations, and the circulation of adjacent water, all of which help to regulate the climate of Australia.

2. PRESSURE AND WIND

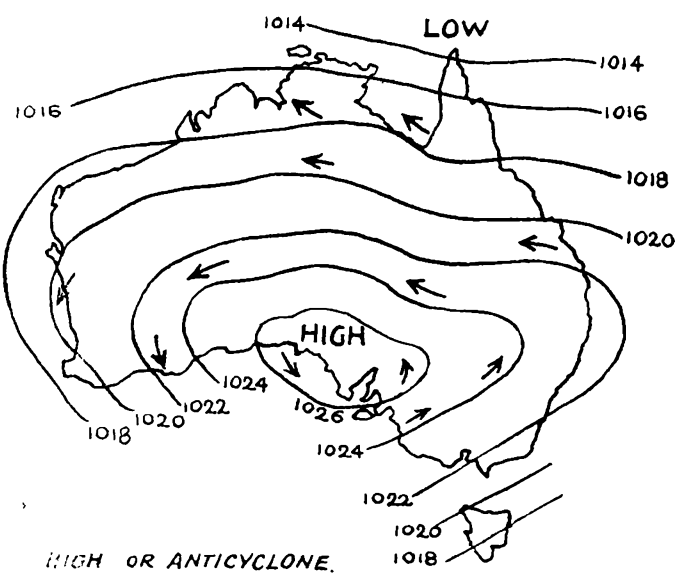
(a) The Australian weather is controlled by three belts of barometric distribution. The dominant feature is the high pressure ridge, which is part of the high pressure belt of the Southern Hemisphere, and which appears on the mean isobar map of every month of the year. The high pressure belt represents a region which is traversed by a constant procession of anticyclones, which move in a general direction from west to east. The path of these anticyclones is between latitudes 42° S. and 30° S., their paths oscillating from season to season, being most northerly during winter and spring and most southerly during summer.

On the northern side of the anticyclonic belt lies the tropical low pressure belt. Coinciding with the thermal equator fairly

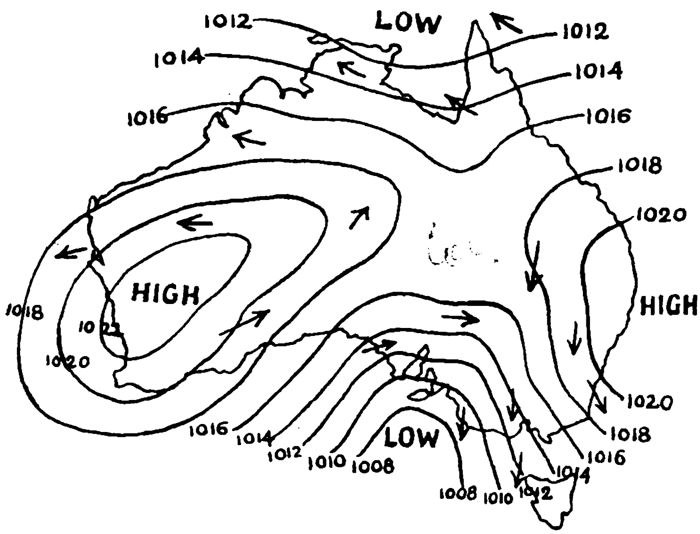
closely this belt (later the other pressure belts) follows the apparent movement of the sun, being farthest south in January and farthest north (in the Northern Hemisphere) in July. Atmospheric depressions, of varying degrees of intensity, develop in this low pressure region and they move in a general west to east direction, or in a direction between south and east. Because of the northern location of the low pressure belt in winter these depressions are not in evidence over the Australian continent during that season.

A striking feature of the climate of southern Australia is the association of the rainfall with storms of the third pressure belt, known as depressions or "lows" of southern origin, and whose paths are generally south of latitude 40° S. These southern disturbances mainly affect the southern and south-eastern sections of Australia, and are most in evidence during winter when the anticyclonic track is farthest north. They generally appear on the chart as a trough occuring between successive anticyclones. Sometimes the lower pressures between successive anticyclones are merely in the form of a "col," that is, there is a continuous ridge of high pressure. Sometimes, however, the ridge of high pressure is broken down by a well-developed trough between successive anticyclones which connects the low pressure on the north, and that on the south, of the continent, the trough extending northwards, and the northern low extending southwards, as a tropical "tongue" or "dip." Occasionally, there is a fully developed depression between the anticyclones moving across Australia.

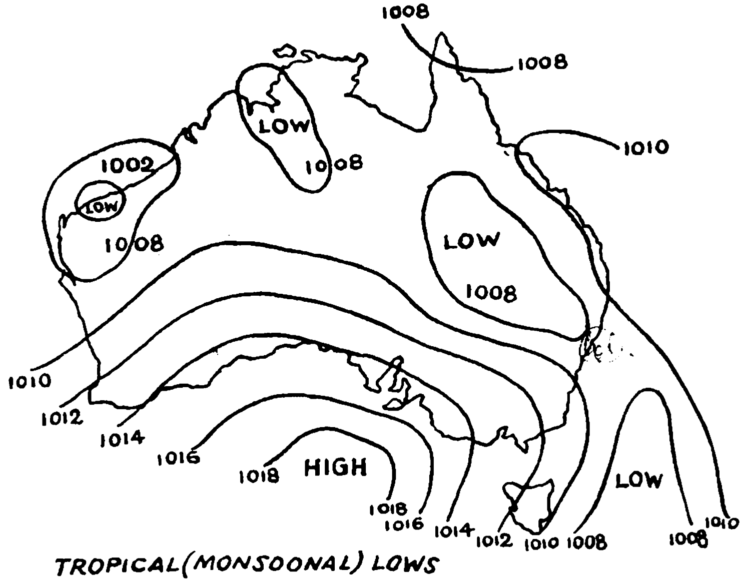
(b) The following are examples of the three controlling belts of barometric distribution:—



HIGH OR ANTICYCLONE.



SOUTHERN LOW and TROPICAL LOW and SUCCESSIVE ANTICYCLONES



TROPICAL (MONSOONAL) LOWS AFFECTING NORTHERN AUSTRALIA.

(c) The dominant winds are the trade winds of the north, and the variable westerly winds in the south. The trade winds blow out of the subtropical belt from about latitude 30° S. to the Equator. On the poleward side of the high pressure belt,

the prevailing winds are north-westerly, but the conditions are much more disturbed and irregular from day to day than in the north. This is due to the fact that southern Australia lies in the path of the anticyclones for the greater part of the year. Hence the winds change from south through S.W. or S.E. to north, as the anticyclones pass over a locality.

The whole northerly portion of Australia is at times under the influence of the trades. Their approximate movements during the year are given in the following table (Taylor "Australian Meteorology").

Month . . .	April, May	June, July	Aug., Sept., October	Nov.	Dec.-Jan.	March
Northern Limit . . .	5° S	0° S	5° S	10° S.	15° S-E 25° S-W	10° S-E 20° S-W
Southern Limit . . .	28° S	22° S.	25° S	28° S.	27° S-E 32° S-W	22° S-E 30° S-W

The prevailing winds around Australia show the relationship of the winds to the controlling pressure system, and may be briefly described as follows:—

(i) **The North Coast—from Cambridge Gulf to Cape York**

The dominant winds throughout the colder months are confined to the S.E. or eastern quarters. This region is part of the trade wind belt. In summer, the N.W. of Australia is subjected to strong insolational heating, and "lows" predominate. These cause a flow of air from the west and N.W., and the series of variable or westerly winds are produced. As the sun moves to the north again, the wind changes to an easterly, and, from March, to winds more from the S.E. In this region calms are frequent during the transitional months (October, November, April, May) between the season of the trades and that of the monsoons, and throughout the year where places are sheltered from these seasonal winds.

(ii) **.The Queensland Coast—from Cape York to Brisbane**

The winds are rather constant, and change little in direction. In summer the wind is a dominant east wind, and in the cooler months a dominant south-east wind.

(iii) **The New South Wales Coast**

The winds are variable being controlled by the passage of successive anticyclones.

(iv) **The Southern Coasts—from Cape Howe to Cape Leeuwin**

This region occurs on the border line between the high pressure belt and the region of prevailing westerlies. The centres of the southern depressions lie somewhat south of the continent, so that this area is controlled by the westerlies which blow between the belt of "highs" and the belt of "lows." These are the most pre-

dominating winds, but are interrupted by "south-wandering highs" or "north-wandering lows."

(v) **The West Coast—from Cape Leeuwin to N.W. Cape**

The predominating winds are south and west. The southern component is more predominant during summer and autumn, the westerly in winter. However, again, the predominance of such winds varies in incidence with the passage of the anticyclones coming on to the mainland from the Indian Ocean, and particularly in the northern half of this section in winter, the winds vary from S., S.E., through E., N.E. to N., with quite a considerable frequency of N.E. winds.

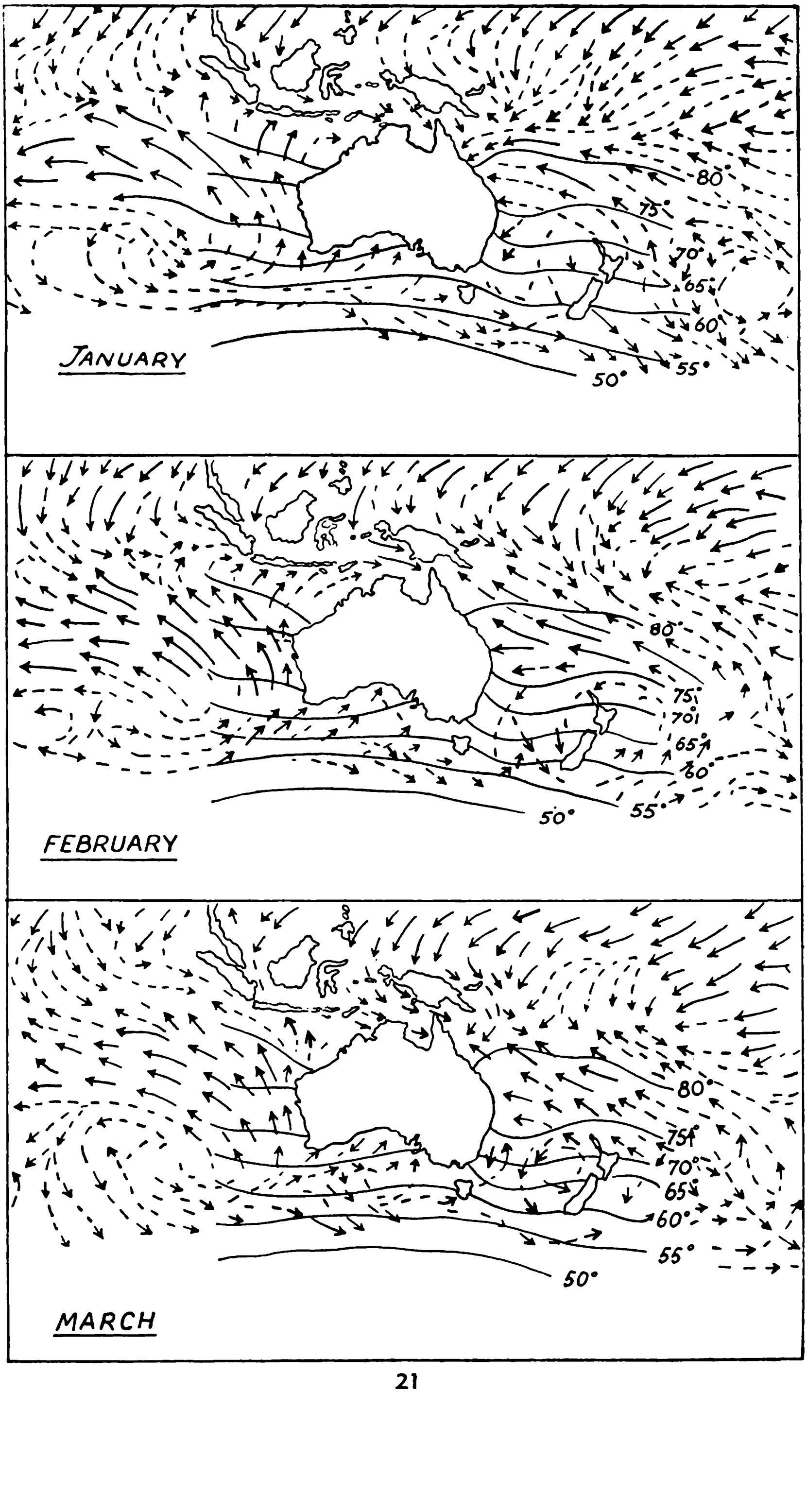
(vi) **The North-West Coast—from N.W. Cape to Cambridge Gulf**

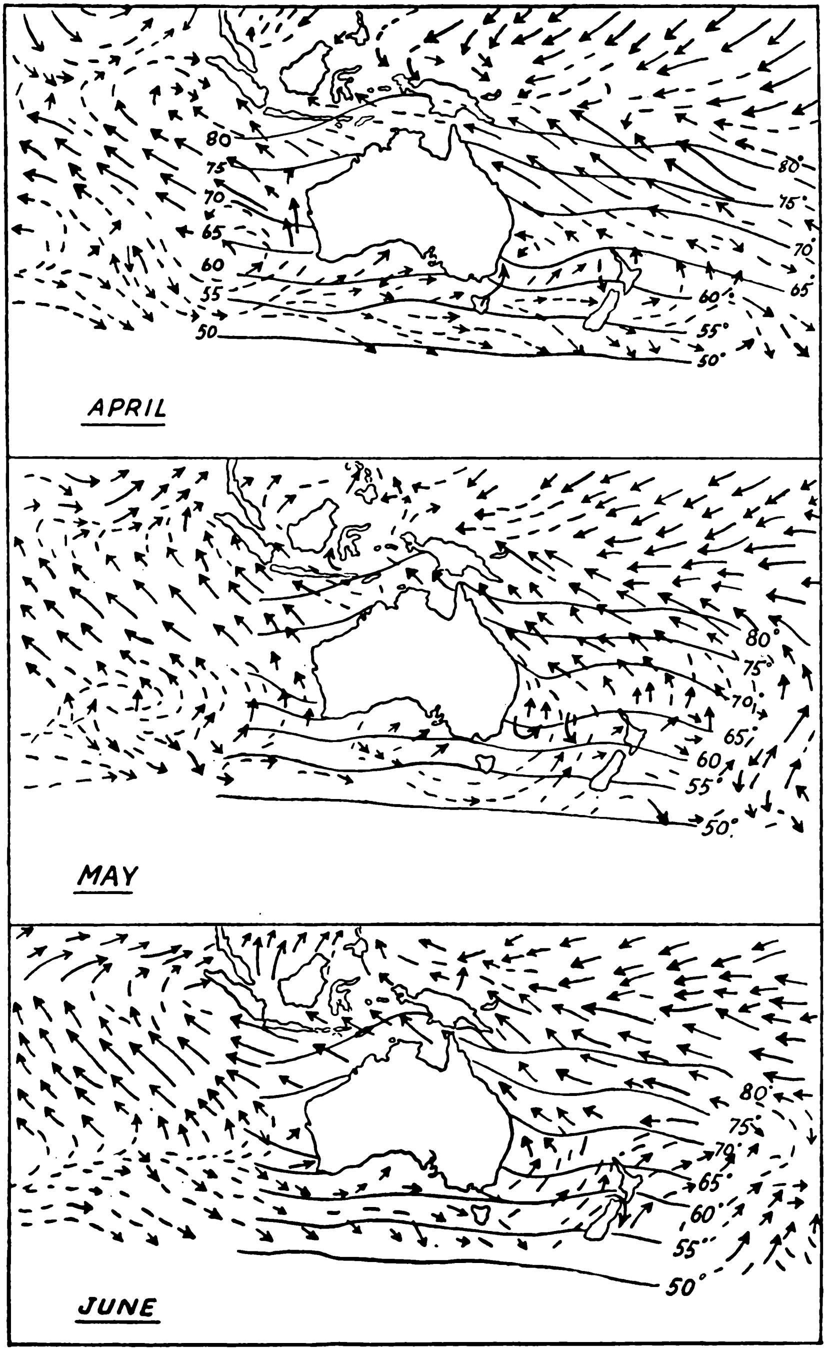
This region is dominated by the trades (S.E. to E.) during the cooler months, but during summer, owing to the relatively constant low pressure existing over the N.W. of Australia, the winds swing round to the S.W.

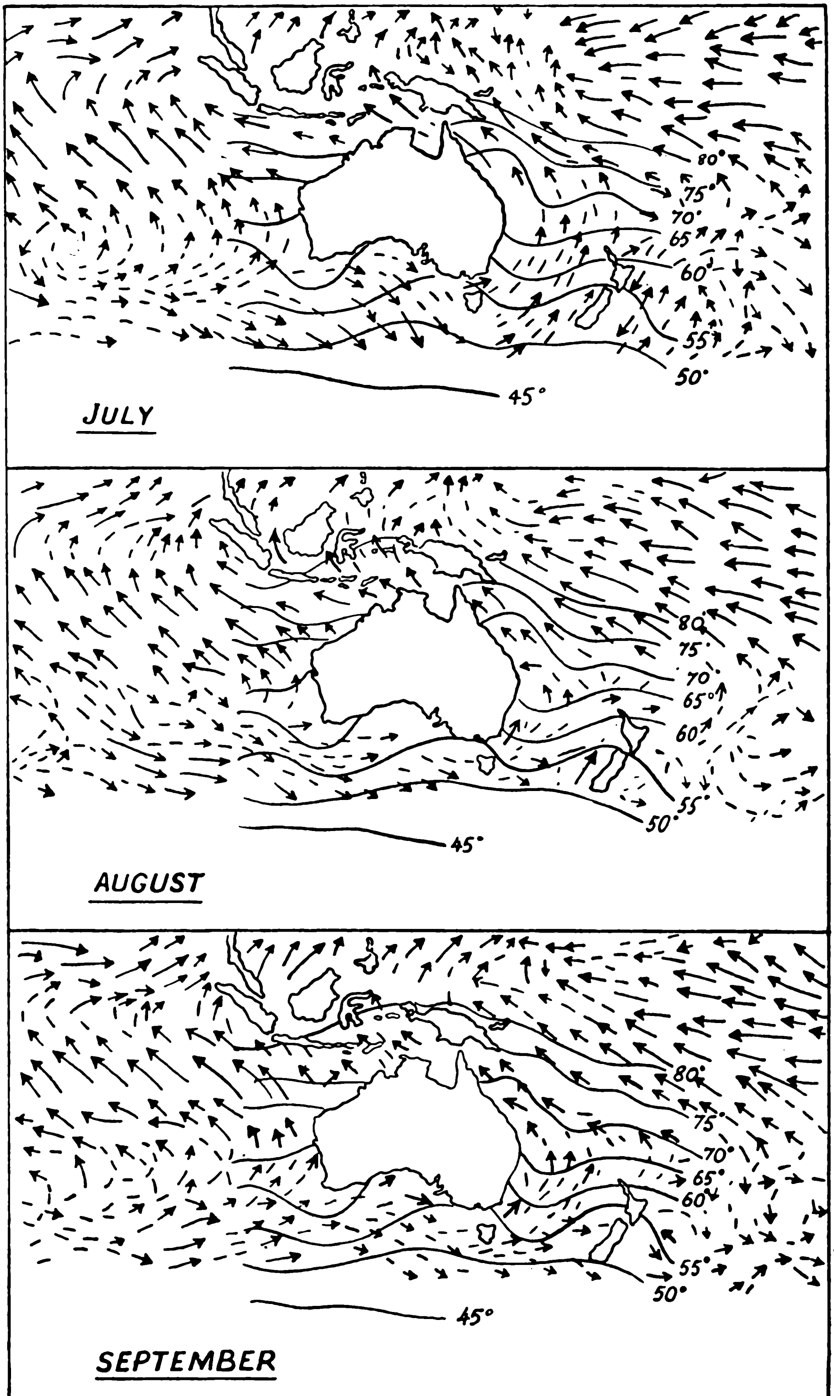
3. **MEAN WIND TRAJECTORIES**

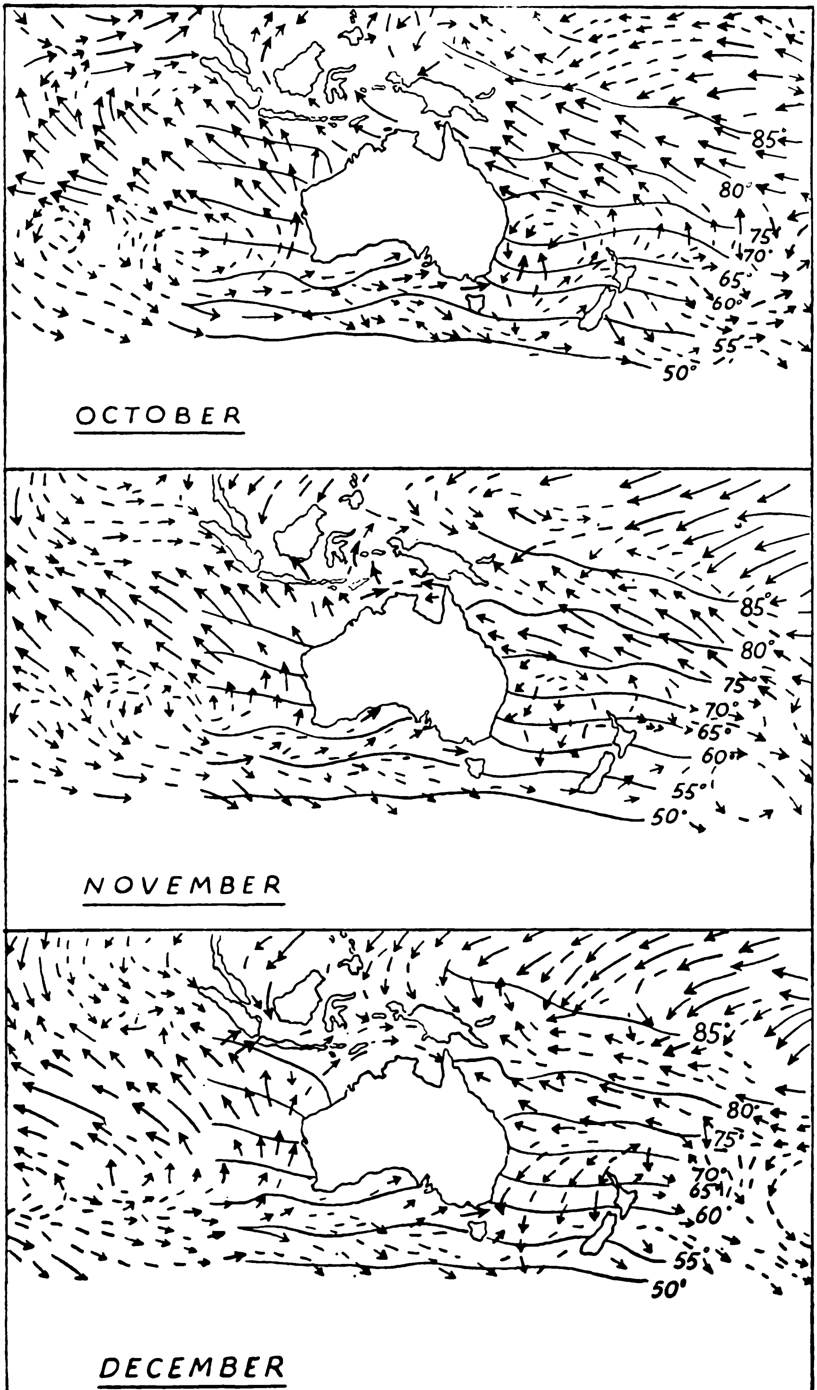
The accompanying diagrams* show the mean monthly winds which blow over the seas adjacent to the Australian coastline, and which will in turn affect the weather and climate of Australia. Superimposed are the mean monthly isotherms which will serve to give an indication of the temperatures with which the winds arrive at the coastal areas.

"*The Mean Transport of Air in the Indian and Southern Pacific Oceans."—Depperman.


80°
75°
70°
65°
60°
55°
50°
JANUARY
80°
75°
70°
65°
60°
55°
50°
FEBRUARY
80°
75°
70°
65°
60°
55°
50°
MARCH


80
75
70
65
60
55
50
80°
75°
70°
65
60°
55°
50°
APRIL
80°
75°
70
65
60
55°
50°
MAY
80°
75°
70°
65°
60°
55°
50°
JUNE


80°
75°
70°
65°
60°
55°
50°
45°
JULY
80°
75°
70°
65°
60°
55°
50°
45°
AUGUST
80°
75°
70°
65°
60°
55°
50°
45°
SEPTEMBER

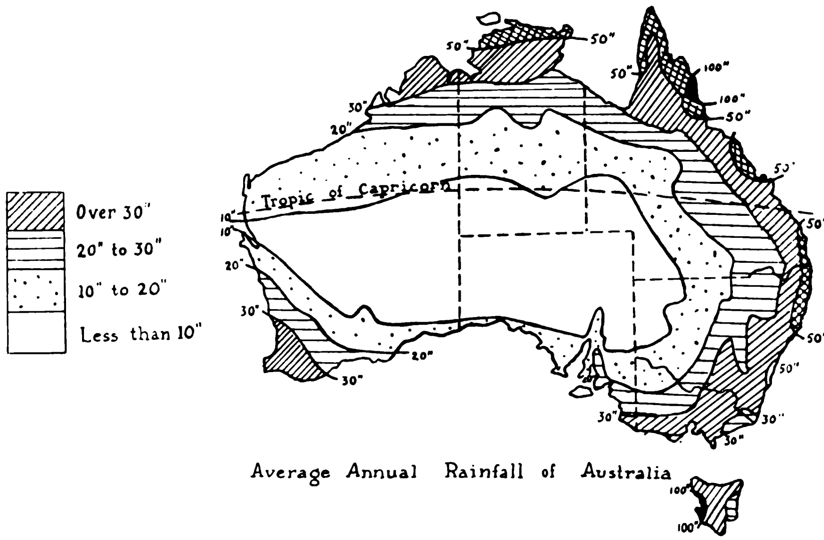


85°
80°
75°
70°
65°
60°
55°
50°
OCTOBER
85°
80°
75°
70°
65°
60°
55°
50°
NOVEMBER
85°
80°
75°
70°
65°
60°
55°
50°
DECEMBER

4. RAINFALL

(a) **Isohyets**

The figure below .shows the average annual rainfall of Australia.



Average Annual Rainfall of Australia

On this map note particularly the position of the 10″ (often taken as the approximate boundary of semi-desert conditions) and 30″ isohyets. The 10″ isohyets includes a very large part of Central Australia, and extends to the west coast and the Bight —roughly, a third of the continent. The driest part of Australia is the Lake Eyre district, where the annual average is only 5″. Because of high temperatures and great evaporation in the north, the arid area really extends beyond the 10″ isohyet. The area with a heavier rainfall than 30″ is confined to a narrow belt on the north coast and along the eastern margins, a small area in Swanland, and most of Tasmania. Only small areas of the continent have more than 50″ of rainfall annually, viz., the north-eastern coastal areas, the far north of Arnhem Land, western Tasmania, and small highland areas of Victoria and New South Wales.

(b) **Rainfall and Wind Belts**

The rainfall of Australia depends upon the position of the continent in relation to the two great wind belts, viz., the "trade winds" and the "westerlies." The "trade winds" strike the eastern shores as far south as latitude 30° S., and, in rising over the eastern highlands, cause heavy rain. The wettest part of Australia is on the north-east coast of Queensland, where several stations in the neighbourhood of Cairns and Innisfail

have an annual rainfall of about 150 inches. Except in the region of the eastern coastlands, the prevailing E. to S.E. winds are offshore and bring little rain.

The "westerlies" influence the rainfall of southern Australia, and are associated with low pressure conditions, and the southern sides of anticyclones in winter when the anticyclonic track is furthermost north. The heaviest rainfall is experienced where these winds are forced to rise over highland areas, such as the Darling and Stirling Ranges and the Swanland region, the Flinders Ranges and Mount Lofty Ranges in South Australia, the Grampians and Pyrenees of Central and Western Victoria, and the coastal ranges of western Tasmania. A very wet region is the western part of Tasmania where Lake Margaret, for instance, has an annual average of about 150 inches.

The northern part of the continent comes under the influence of the on-shore monsoon winds during the summer months, particularly January, February and March, and receives a good rainfall during that season. The monsoonal winds are a vigorous N. to W. circulation, and enter northern Australia along the coast from about Darwin to Groote Island, and further south in the Gulf of Carpentaria, and extend eastwards towards Coen, sometimes reaching as far east as Willis Island. They arrive as a relatively cold unstable air mass and undercut and uplift a relatively warm equatorial air mass which has a high water vapour content. They yield the most disturbed, and the most rain-productive weather of the wet season (except the tropical cyclone) and influence the weather of northern Australia from about January to March, arriving near the Australian coast usually within the first two weeks of January. The period prior to this, viz., October to December, is a period of thunderstorm rains. During this period, the high pressure systems are weakening and receding southwards with the advance of the thermal equator, the degree of insolational heating is increasing rapidly, and the water vapour capacity of the air is increasing with the increase of temperature. This section also receives heavy precipitation from tropical cyclones, particularly the N.E. and the N.W. sections, the cyclones entering the N.E. coast between Cooktown and Mackay, and the N.W. coast between Onslow and Derby.

(c) The Seasonal Occurrence of Australian Rainfall

The outstanding feature is that there is a marked difference between northern and southern Australia, the former having a summer maximum of rainfall, and the latter a winter maximum. While there is a maximum of rainfall in the summer months in northern Australia, the winter is a period of marked dryness; Darwin, for instance, receives 80% of its rainfall in four summer months (December, January, February and March) and less than 2% in the four winter months (June, July, August and Septem-

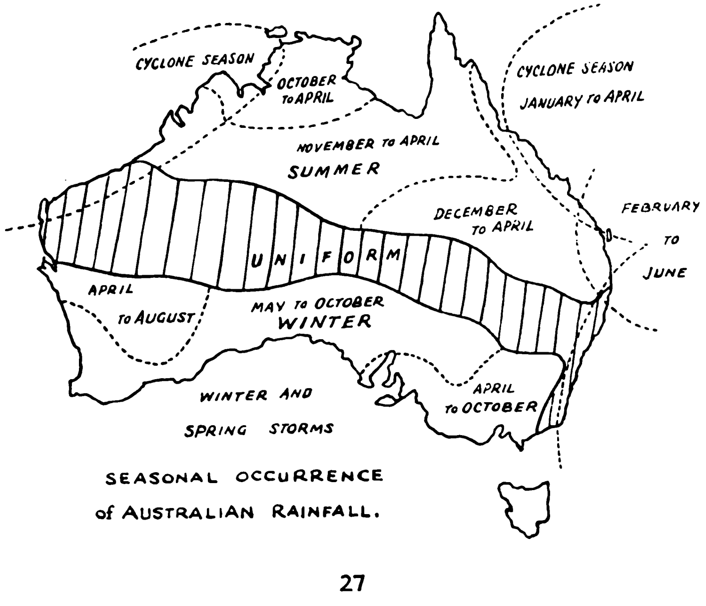
ber). On the Queensland coast, the summer maximum is still in evidence, but there are heavier falls of rain in winter than further inland and in northern Australia. Towards the south, there is still a summer maximum on the north coast of N.S.W., but the amounts received in other seasons form a greater proportion of the total.

In central N.S.W., the rainfall is more evenly distributed throughout the year, with slight maxima which vary in time at different places, but which occurs chiefly in autumn and early winter.

The winter maximum of rain in the south is most pronounced in Swanland, the southern districts of South Australia, and central and western Victoria. The summer is very dry, but not to the same degree as the winter of the north. East of Melbourne and in eastern Tasmania, the distribution of rainfall is more like that of central N.S.W.

The seasonal rainfall of Australia is closely related to the seasonal change in position of the controlling pressure belts. Most of the summer rainfall of the north is caused by the monsoonal winds in summer, and by the southward position of the equatorial low pressure belt.

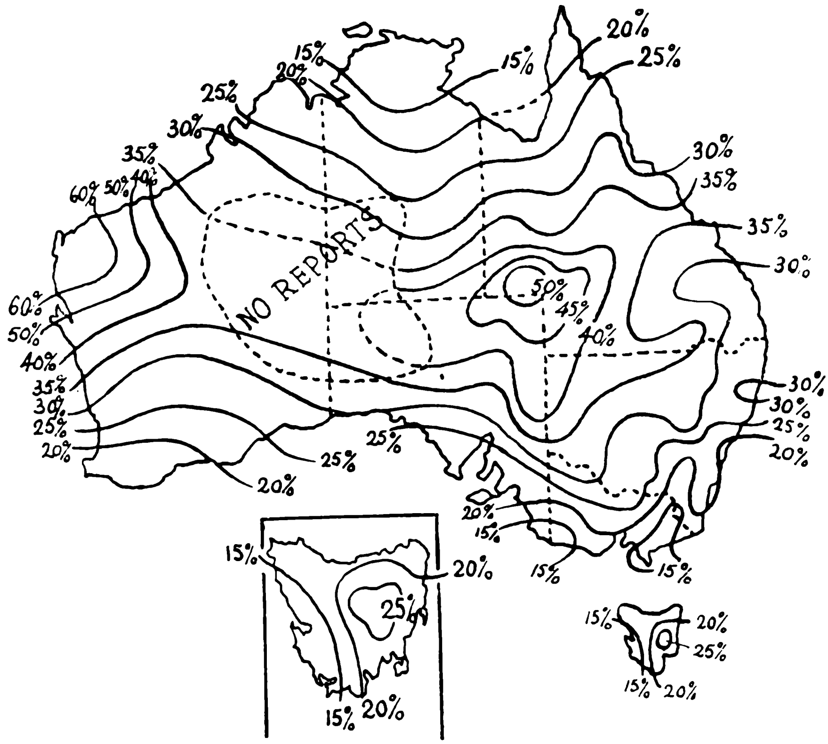
Most of the rain of southern Australia is connected with low pressure conditions. These are most frequent in winter when the southern low pressure systems are passing along a more northerly track.



SEASONAL OCCURRENCE of AUSTRALIAN RAINFALL.

(d) The Variability of Rainfall in Australia

A consideration of the variations from the mean which are likely to occur is another important consideration in addition to that of the annual average rainfall. The following map, prepared by Mr. Barkley, indicates the range of variability which various districts may expect in their annual precipitation.



Variability of Rainfall

The figures shown on the map are the Standard Deviation from the Mean Annual Rainfall shown as a percentage of that mean. The higher the percentage, the less reliable is the rainfall.

In general, there are two regions in which variability reaches a maximum, one in the central coastal area of Western Australia, and the other in the S.W. corner of Queensland. In addition to these extreme zones, more than half of the continent has a rainfall variation of 30% or over. This proportion includes most of the country with less than 10 inches of precipitation in the south of the continent and with less than 20 inches in the north.

In Erwin Biel's world map of variability of annual rainfall, the variability of the annual rainfall in almost every part of Australia is shown to be greater than in any part of Great Britain, while about 80% of the continent has a greater variability than any section of Europe.

Added to this, for Australia as a whole, rainfall not only tends to diminish with increase in distance from the coast, but reliability of rainfall, i.e., the likelihood that rainfall for any one year will equal the average for a district, diminishes also.

5. HUMIDITY

(a) Relative Humidity in Australia

By plotting the relative humidity data for Australia on a series of monthly maps, the lines of equal humidity are found to be concentric and more or less parallel to the coastline. The highest relative humidities are found to be in the vicinity of the coastal regions, the values decreasing with increasing distance from the coast.

The two extreme months appear to be June, when the general humidity of the continent is greatest, and October, when it is least. The centre of lowest humidity moves north and south with the apparent movement of the sun, being near Powell's Creek (N.T.) in July and near Oodnadatta (S.A.) in January. There seem indeed to be two summer centres, one just north-east of Lake Eyre and the other north-east of Wiluna.

The lines of equal relative humidity emphasise the seasonal occurrence of the Australian rainfall. In northern Australia the highest relative humidities occur during summer and the lowest during winter. Over southern Australia the position is reversed, with highest relative humidities in winter and the lowest in summer. In the hottest region of Australia (the north-west around Marble Bar and the Pilbara district) the humidity is by no means high. At Broome, further north and along the coast, the humidity is 71%, and it increases to 78% at Darwin in January. All down the east coast the heavy rainfall leads to much greater humidities than along the west coast of the continent. But as the rainfall decreases rapidly towards the interior the region with humidities over 70% in midsummer is very narrow. An interesting feature is the influence of the mountain region in south-eastern and north-eastern Australia. The effect is to produce higher relative humidities, as is shown by the bulge over south-eastern Australia in the 80% isopleth in the July chart. In fact one of the most humid stations on record is Kiandra, situated near Mt. Koscuisko and 4,640 feet above sea level. Here during the eight months from March to September the humidity is over 77%.

The Movement of Humidity.—In January only the northern coast and extreme south-east and south-west corners of the continent have humidities over 70%. The maximum is 82% at Thursday Island. Western Tasmania (Cape Sorrell) also records high humidities, although the region in central Tasmania is much drier.

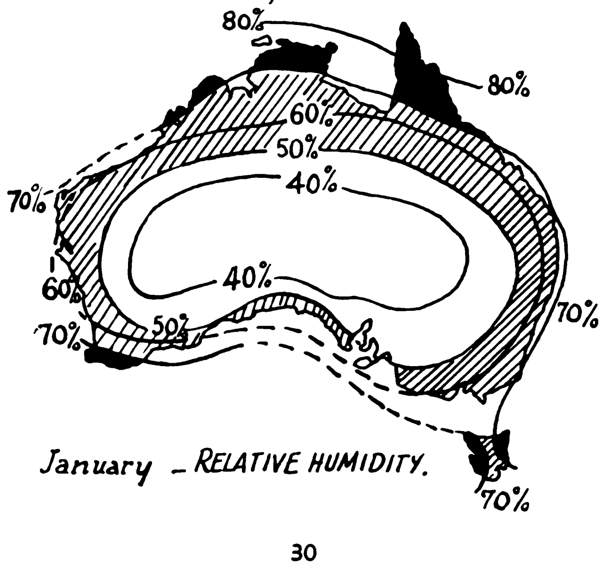
In February and March the conditions are much the same. In April the south-east section becomes more humid, and parts of the mountainous area of the south-east corner and the west coast of Tasmania record over 80% relative humidity. In May the arid centre moves perceptibly north. The humid area (over 70%) is very much wider in the S.E. with the whole of Tasmania and the south-east highlands over 80%.

In June the whole of Victoria and Tasmania and the elevated portions of N.S.W. record over 80%, so also do the S.W. corner of Western Australia and Thursday Island. Kiandra shows a maximum over 92%.

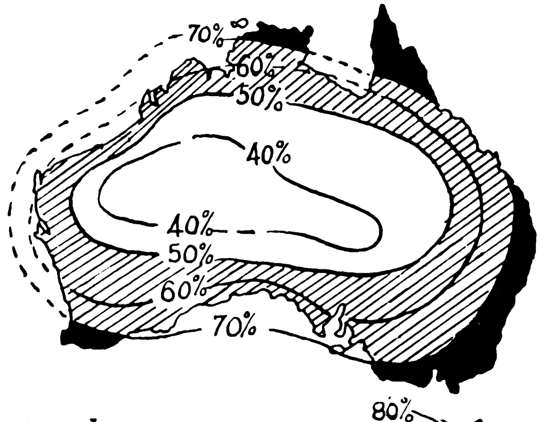
In July conditions are almost the same as in June. In August a rapid retreat southwards of the humid zone begins, the humidities in the southern half of Australia beginning to decrease rapidly. The figures in the S.E. highlands are still high.

In September the central area below 40% broadens greatly, and in October reaches its maximum extent. This is the least humid month in almost every locality in Australia.

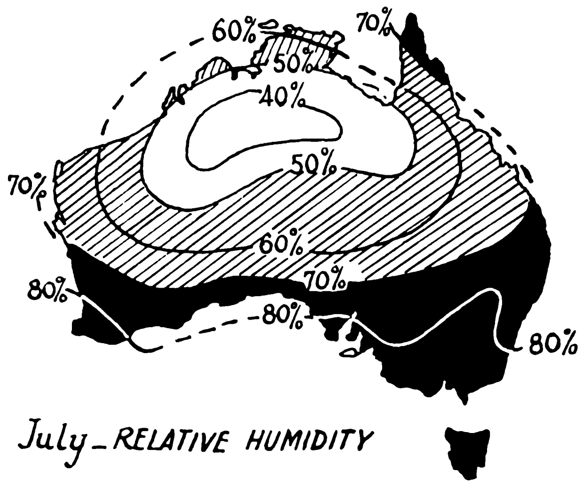
In November conditions are very similar. In December the northern coast records again exceed 70% from Darwin to Townsville but conditions remain dry in the south.



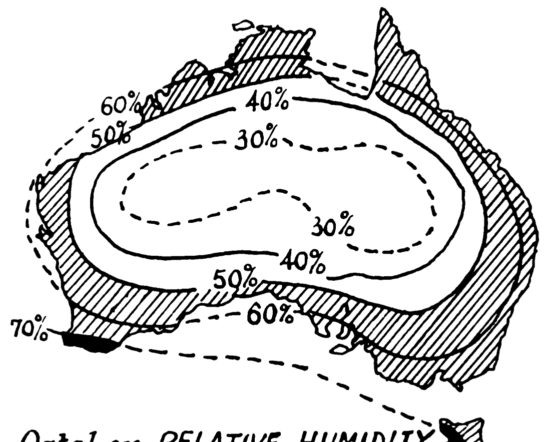
January – RELATIVE HUMIDITY.



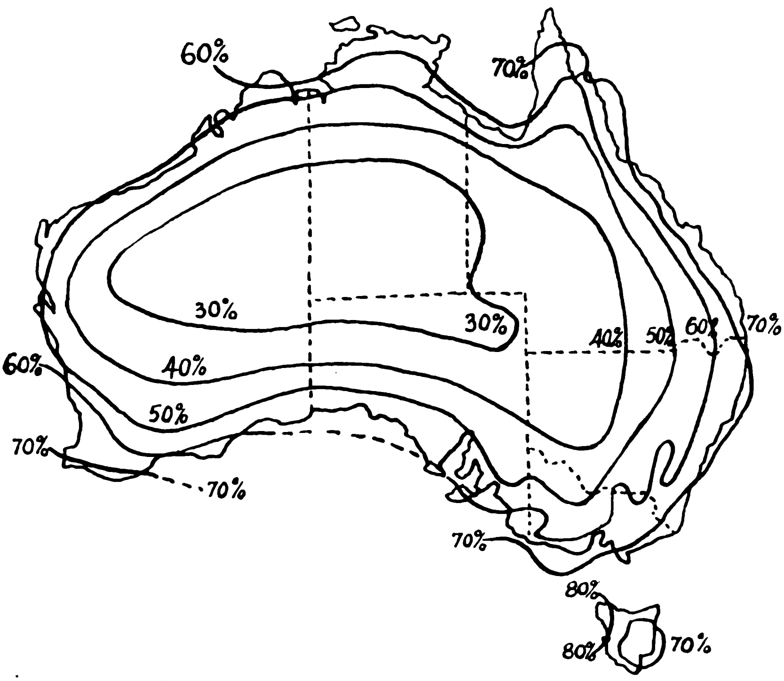
April—RELATIVE HUMIDITY



July—RELATIVE HUMIDITY



October—RELATIVE HUMIDITY



NORMAL. 9. a.m. RELATIVE HUMIDITY.

(b) **Wet Bulb Isotherms**

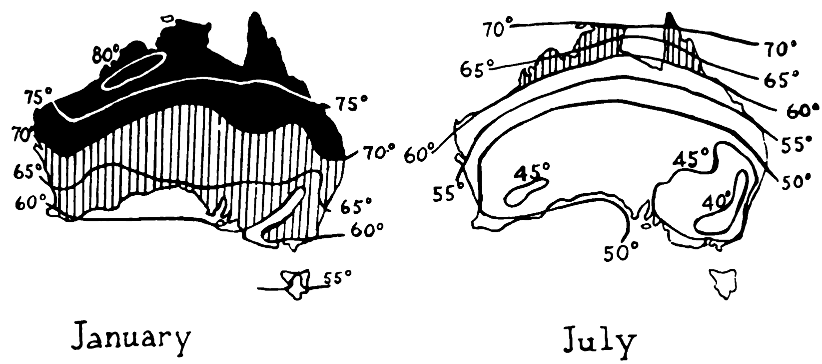
The wet bulb isotherms are not very different from the ordinary isotherms. When the rainy season is affecting a region, then the evaporation is slow and the wet bulb reads nearly the same as the dry bulb. In the tropics, when the "mugginess" is marked and discomfort is considerable the wet bulb readings are at their maximum. In midsummer the whole of the tropical region shows high wet bulb temperatures, for it is hot and wet at the same time. In midwinter the north is experiencing the dry season, and although the dry bulb readings are high, evaporation is so active that the wet bulb readings remain low. In this period only the extreme northern parts around Darwin and Cape York have readings over 70° F.

In the south the dry bulb temperatures are lower, and the wet bulb readings are low but they differ very little from the dry bulb readings particularly during the winter months.

February is usually the most oppressive month in Sydney and Melbourne. The average wet bulb temperatures for this month are, however, only 65° F. and 60° F. respectively, while at Melbourne the extreme reading for any day of the year rarely exceeds 75° F. Brisbane has two months with an average wet bulb over

70° F. At Mackay such high wet bulb readings exist for six months in the year; at Cooktown for ten, and at Thursday Island practically all the year round.

The wet bulb temperatures emphasise the humidity factor. This is an important factor in dealing witih tropical, subtropical and warm temperate regions, as an excess of temperature is never so important as an excess of humidity.

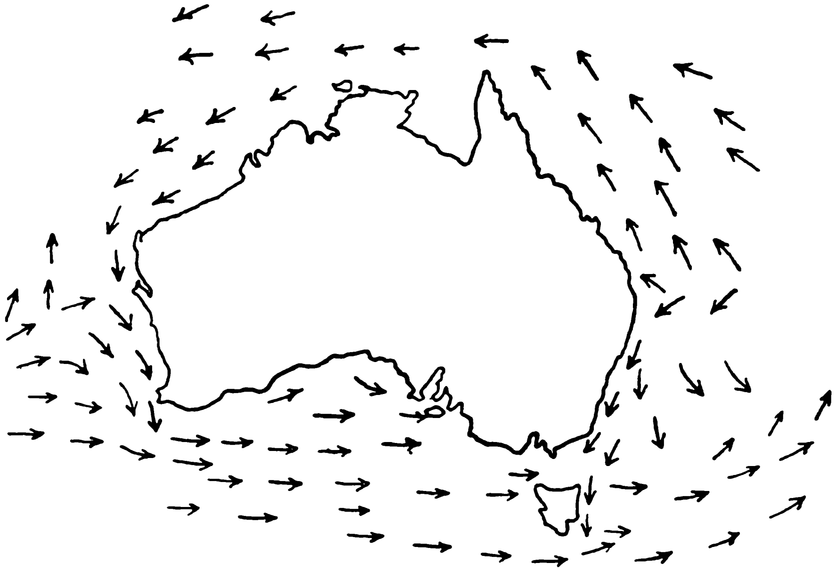


Average Wet Bulb Charts (after H. A. Hunt). Regions shown in Black have a "Muggy" Climate.

6. OCEAN CURRENTS

The ocean currents around the Australian coast are important influences on the weather and climate of Australia. Winds which blow over warm currents will absorb more moisture, and on reaching land will give more rainfall than winds which blow across cold currents. On the eastern coast, warmer conditions are carried as far south as Tasmania by the eastern Australian branch of the warm equatorial current. The relatively drier west coast and the greater part of the southern coast come under the influence of two branches of the cold west wind drift. The cold current along the west coast of Australia combines with the frequency of offshore winds to bring desert conditions right to the coast. At the eastern end of Bass Strait, to the north-east of Tasmania and along the waters adjacent to the Gippsland coast, is the meeting place of relatively warm waters of the east Australian coast and the cold waters through Bass Strait, and result in differences of many degrees in the temperature of adjacent bodies of water, and also in the air over the waters, which conditions are favourable for the formation of low stratus and fog during the winter months and August and September, particularly with northerly winds down the east coast of New South Wales on the rear of a "high."

The accompanying diagrams show the mean currents influencing the coasts of Australia, but, at the same time, it must be borne in mind that ocean currents are very variable, particularly in the shallow waters adjacent to coastlines, and where the winds are variable in direction.

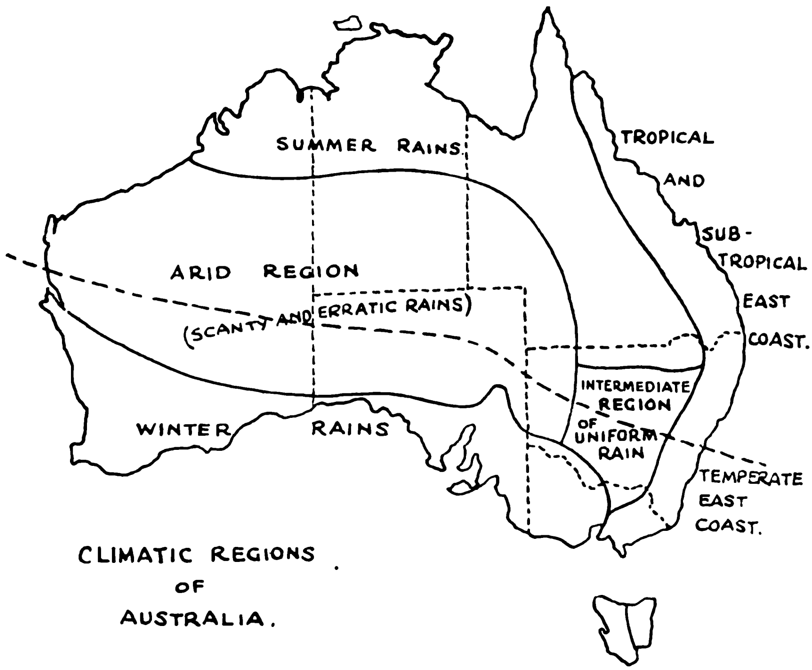


Ocean Currents. August – September

Ocean Currents. February – March

7. THE CLIMATIC REGIONS OF AUSTRALIA

The continent of Australia can be divided into a number of regions, which differ from one another chiefly according to the seasonal occurrence of rainfall. The boundaries between these regions are very difficult to define; in fact, the boundaries should be drawn as a zone of transition rather than a line.



(a) Tropical Monsoon Region—Summer Rain Region

The summer rain region has two well-marked seasons, the "wet" and the "dry." The "dry" season continues almost rainless till the end of September. During this season the weather is influenced by the dry off-shore trades, and is mainly a period of clear skies and very low rainfall. Then, with the apparent movement of the sun southwards, the heat increases, the track of the anticyclones tends further and further southwards, the trades recede southwards, and northern Australia comes under the influence of the tropical low pressure system. Thunderstorms begin in October and become more frequent and violent during November and December. Towards the end of December the monsoon sets in, interrupted at times by calms. The sky becomes overcast with heavy clouds and rain falls frequently. The rainy season continues till April, during the month of which the monsoonal influence is receding, and the trades advancing northwards. The rain fall is greatest, over 60 inches, on the north coast round Darwin, and decreases southwards to 20 inches.

This region has warm conditions, with more than eight months having a greater average temperature than 68° F.

	J.	F.	M.	A.	M.	J.	J.
Darwin:							
Rainfall . .	16·1	12·9	10·0	4·2	0·7	0·1	0·1
Temperature	84	84	84	84	82	77	77
Wyndham:							
Rainfall . .	7·5	6·4	4·6	0·9	0·2	0·1	0·1
Temperature	88	87	87	86	81	77	76
Cloncurry:							
Rainfall . .	4·9	5·1	2·6	0·9	0·4	0·4	0·5
Temperature	87·3	85·0	83·1	77·8	71·0	64·2	61·5

	A.	S.	O.	N.	D.	Annual Total	Mean Range
Darwin:							
Rainfall . .	0·1	0·5	2·1	4·8	10·4	62·0″	
Temperatnre	79	83	85	86	85		9°
Wyndham:							
Rainfall . .	0·0	0·1	0·5	2·0	4·5	26·9″	
Temperature	79	84	88	89	89		13°
Cloncurry:							
Rainfall . .	0·1	0·4	0·4	1·2	3·0	19·9″	
Temperature	67·0	72·8	82·5	85·2	88·0		26·5°

(b) **Tropical and Subtropical East Coast—Region of Rain in all Seasons with Maximum in Summer.**

Although there is a summer maximum of rainfall, the total for the remaining months of the year is greater than in the monsoonal area. The Queensland coast has rain all the year, most in summer and autumn, and least in spring. The rainfall is greatest near the coast itself, which has about 50 inches in the south of the State, and, in the vicinity of the Bellenden Ker Ranges, the annual total exceeds 140 inches. There is a rapid decrease towards the west, to only 30 inches south- east of the Gulf of Carpentaria. Along the north coast of N.S.W. there are also heavy coastal rains, well distributed throughout the year.

The summers are hot and the winters warm; in the tropical north the average temperature for eight months is greater than 68° F. The southern boundary is fixed where less than four months are warmer than 68° F. Kempsey on the Macleay River has five months with an average temperature over 68° F., while Taree on the Manning has only three such months, and so the boundary between the subtropical and the warm temperate coastal regions is fixed between these two rivers.

	J.	F.	M.	A.	M.	J.	J.
Cairns:							
Rainfall . .	16·6	15·5	17·9	11·6	4·3	2·9	1·6
Temperature	82	82	80	78	74	71	70
Harvey Creek:							
Rainfall . .	30·9	22·2	32·2	22·2	13·2	8·0	4·2
Brisbane:							
Rainfall . .	6·5	6·3	5·7	3·7	2·8	2·8	2·3
Temperature	77	74	74	70	64	60	58

	A.	S.	O.	N.	D.	Annual Total	Mean Range
Cairns:							
Rainfall . .	1·7	1·7	2·1	3·8	8·9	88·6"	
Temperature	71	73	77	79	81		12°
Harvey Creek:							
Rainfall . .	5·4	3·7	3·8	8·1	11·7	165·6"	
Brisbane:							
Rainfall . .	2·1	2·0	2·6	3·7	4·9	45·4"	
Temperature	60	65	70	74	76		19°

(c) Temperate East Coast—Rainfall in all Seasons with Maximum in Autumn and Early Winter

This region extends along the south-east coast from the Macleay River to Port Phillip, and includes eastern Tasmania. The average temperature exceeds 68° F. in less than four months, but the winters are not severe, fewer than four months having average temperatures under 50° F. The range of temperature from winter to summer is also greater in this region than in the coastal lands to the north.

This section has no "dry" season. The rainfall is fairly evenly distributed month by month with not very large differences between the seasons. There is, on the whole, a maximum during the autumn and early winter months. The summer temperatures are not as high as in the interior, but the heat may be more oppressive because of the high relative humidity. Near the coast the north-easterlies are very regular breezes in summer, and this is a period when the "southerly burster" influences occur.

	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Annual Total	Mean Range
Sydney:														
Rainfall . .	3·7	4·2	5·0	5·5	5·1	4·8	4·8	3·0	2·8	2·8	2·8	2·8	47·3″	19°
Temperature	72	71	69	65	59	55	53	55	59	64	67	70		
Canberra:														
Rainfall . .	1·5	1·6	2·2	1·5	2·3	2·2	1·7	2·0	1·7	1·9	2·0	2·0	22·6″	26°
Temperature	69	69	64	56	48	44	43	45	50	55	61	67		
Bairnsdale:														
Rainfall . .	2·7	2·0	2·5	2·0	2·1	2·2	2·0	1·6	2·3	2·6	2·0	2·1	26·1″	19°
Temperature	65	66	62	57	52	48	47	49	53	57	60	63		
Hobart:														
Rainfall . .	1·9	1·5	1·7	1·9	1·9	2·2	2·1	1·8	2·1	2·3	2·5	2·0	23·9″	.91
Temperature	62	62	59	55	51	47	46	48	51	54	57	60		

(d) **The Winter Rain Region**

This region comprises southern Australia and western Tasmania. This climatic region covers the S.W. corner of Western Australia, a narrow region along the coast facing the Australian Bight, the S.E. of South Australia, western and central Victoria and western Tasmania. Along the Australian Bight the area receiving more than 10 inches is extremely narrow. The effect of the Flinders Range, which lies athwart the westerly winds, in improving the rainfall of South Australia is prominently shown in the annual rainfall. In Victoria, particularly towards the N.E., the rainfall becomes more uniform.

The most important feature of this region is the concentration of the rainfall in the winter months, the summer being a period of bright weather with relatively small rainfall. The reliability of rainfall is particularly high. This region comes under the influance of the temperate westerlies, and the southern lows mostly in winter. This is exemplified particularly in the western part of Tasmania, which is one of the wettest places in Australia—the region behind Macquarie Harbour receiving 115 inches of rainfall annually. Rainfall decreases rapidly with distance from the sea, especially in that part of the region on the mainland; the 10-inch isohyet is the approximate northern boundary of this region.

	J.	F.	M.	A.	M.	J.	J.
Perth:							
Rainfall . .	0·3	0·4	0·8	1·6	5·0	6·9	6·7
Temperature	74	74	71	67	61	57	55
Adelaide:							
Rainfall . .	0·7	0·7	1·0	1·8	2·8	3·1	2·7
Temperature	74	74	70	64	58	54	52
Ballarat:							
Rainfall . .	1·4	1·5	1·9	2·1	2·6	2·9	2·5
Temperature	64	66	60	54	49	45	44
Eucla:							
Rainfall . .	0·7	0·5	1·0	1·2	1·2	1·2	0·9
Temperature	70·9	71·2	69·3	66·1	60·9	55·9	54·3

	A.	S.	O.	N.	D.	Annual Total	Mean Range
Perth:							
Rainfall . .	5·8	3·5	2·2	0·8	0·6	34·6″	
Temperature	56	58	61	66	71		19°
Adelaide:							
Rainfall . .	2·5	2·0	1·8	1·1	1·0	21·2″	
Temperature	54	57	62	67	71		22°
Ballarat:							
Rainfall . .	2·8	2·9	2·5	2·0	1·9	27·0″	
Temperature	46	49	53	57	61		22°
Eucla:							
Rainfall . .	1·0	0·8	0·7	0·7	0·4	10·3″	
Temperature	56·3	59·3	62·7	65·9	69·3		17°

(e) The Arid Region—Hot Desert and Semi-Desert

This region comprises a very large part of the total area of Australia, and consists mainly of an undulating tableland 1000 feet-3000 feet high. It lies too far south to be benefited regularly by the monsoon winds, and too far north to be much influenced by the westerlies in winter. The region may be described as a Trade Wind Desert. In the south, the boundary of this region coincides approximately with the 10-inch isohyet, but, in the north, because of the greater degree of evaporation, nature of the soil, and the high variability of the rainfall, it is extended up to the 20-inch isohyet. In the neighbourhood of the Tropic of Capricorn, it extends to the west coast. The scattered rains of the north fall chiefly in January, and, during May and June, in the south. The driest region lies east and N.E. from Lake Eyre, where less than 5 inches is the average annual rainfall. This minimum is coincident with the lowest elevation, Lake Eyre being actually below sea level. Besides having a very low and erratic rainfall, a marked feature of the region is the very high range of temperature both seasonal and diurnal, the winters being quite cool, while the summers may be extremely hot.

	J.	F.	M.	A.	M.	J.	J.
Kalgoorlie:							
Rainfall . .	0·4	0·8	1·0	0·9	1·2	1·2	0·8
Temperature	78	78	73	67	59	54	52
Alice Springs:							
Rainfall . .	1·7	1·5	1·2	0·7	0·6	0·6	0·4
Temperature	83	82	77	68	60	54	53
William Creek:							
Rainfall . .	0·5	0·4	0·8	0·4	0·4	0·7	0·3
Temperature	83	83	76	67	59	54	52

	A.	S.	O.	N.	D.	Annual Total	Mean Range
Karlgoorlie:							
Rainfall . .	0·9	0·5	0·6	0·6	0·7	9·6″	
Temperature	55	60	65	73	77		27°
Alice Springs:							
Rainfall . .	0·4	0·4	0·7	1·0	1·5	10·7″	
Temperature	58	65	73	79	82		30°
William Creek:							
Rainfall . .	0·3	0·4	0·3	0·4	0·3	5·4″	
Temperature	56	62	70	77	81		31°

(f) Intermediate Region of Uniform Rain

This climatic region comprises the area with an annual rainfall of about 10 to 30 inches, and lies on the dry side of the temperate east coast. The seasonal and diurnal ranges of temperature are greater than along the coast.

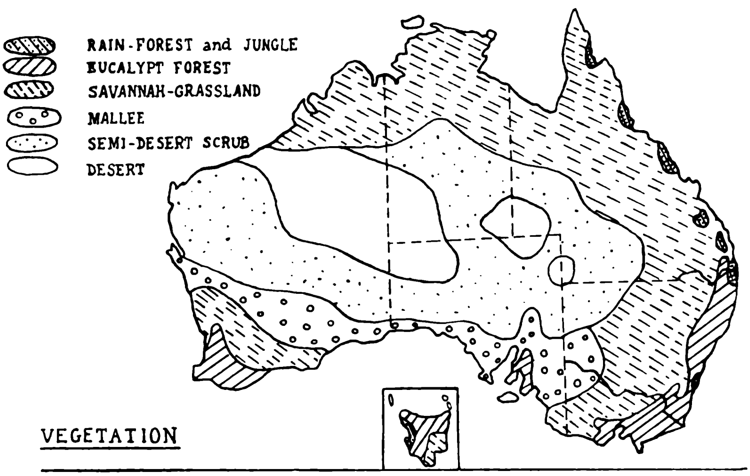
This region is one of fairly uniform rainfall distribution, the summer and winter rains overlapping, and yielding a slight maximum in summer in the north, and in winter in the south. It is the type of climate experienced over the western slopes and plains of N.S.W. and the northern part of Victoria. The region reaches from about Wilcannia, through Bourke to the 30-inch isohyet and S.E. to about Albury.

	J.	F.	M.	A.	M.	J.	J.
Deniliquin:							
Rainfall . .	1·0	1·1	1·3	1·3	1·7	1·8	1·3
Temperature	75	76	69	62	55	50	48
Wilcannia:							
Rainfall . .	1·0	0·8	1·1	0·7	1·0	1·1	0·6
Temperature	81	80	74	65	58	52	50
Dubbo:							
Rainfall . .	2·1	1·9	1·8	1·8	1·9	2·0	1·7
Temperature	79	77	71	64	55	50	47

	A.	S.	O.	N.	D.	Annual Total	Mean Range
Deniliquin:							
Rainfall . .	1·4	1·6	1·5	1·1	1·0	16·1″	28°
Temperature	51	56	61	68	71		
Wilcannia:							
Rainfall . .	0·8	0·7	0·9	0·7	0·8	10·2″	31°
Temperature	54	60	68	75	79		
Dubbo:							
Rainfall . .	1·8	1·9	1·6	1·8	2·0	22·3″	32°
Temperature	51	56	63	71	76		

8. NATURAL VEGETATION OF AUSTRALIA

A considerable variety of vegetation is to be found in Australia. At one extreme are forests, which only grow where the rainfall is fairly heavy and constant. At the other extreme are deserts, in which the rainfall is so scanty or erratic in its occurrence that few plants can survive. Between these extremes are to be found woodlands of various kinds, and grasslands.



VEGETATION

(a) Rain Forest and Jungle

This type is found in comparatively small areas along the east coast, where the rainfall is heavy and fairly constant. Rain forests also occur in Western Australia. They abound in dense undergrowth, ferns and vines, which help to make an almost impenetrable growth. The climate of this region is a high constant temperature, abundant precipitation, high relative and specific humidity.

(b) Eucalypt Forest

This occupies the wetter portions of eastern and southern Australia where rainfall is not heavy enough to support a jungle growth. They lack the dense undergrowth and ferns of the rain forest.

(c) **Eucalypt Woodland**

This area may be considered as grasslands, for the trees (mostly eucalypts of many varieties) are found scattered in a parkland formation. In favourable places, they form patches of forest. They occur in the tropical north, the "downs" in central and southern Queensland, the western slopes of the highlands in N.S.W., South Australia and Western Australia, and the Wimmera district in western Victoria.

(d) **Mallee Scrub**

This is a special variety of eucalypt woodland, developed on limestone soils in the winter rainfall belt in the southern half of the continent. Mallee is a dwarf eucalypt which branches out from the ground in a bush-like fashion. It is sometimes associated with patches of small cypress pines.

(e) **Semi-desert Scrub and Scrub-steppe**

This type occupies the semi-desert area, that is, approximately all the land within the 10-inch isohyet, excluding the true desert. The dominant plants are acacias both in shrub and small tree form. On the southern side, a very important feature is the shrub-steppe, composed of low shrubs (saltbush, bluebush, and cotton-bush) mixed with mulga, sandalwood, and other tall shrubs, and a certain amount of grass during the rainy season. Features of the climate in these areas are wide temperature variations, evaporation exceeding precipitation, most rain falling as showers at rare intervals.

(f) **Desert**

The Great Sandy Desert of Western Australia extends into the north-west of South Australia, where it is known as the Victoria Desert. In the N.E. of South Australia are the Arunta Desert extending into central Australia, and Sturt Desert extending into south-western Queensland. The latter are characterised by gibber plains, but even here, as almost universally in the western desert, parallel sand dunes occur. These dunes are sparsely vegetated with porcupine grass; on the flats between the dunes grow small trees and shrubs, mainly mulga and desert oak. Features of the climate in these areas are high summer temperatures, large diurnal and annual temperature variation, absence of cloud, extreme dryness, dust and sandstorms, and rain at rare intervals.

(g) **Mountain Grassland**

No part of Australia is high enough to be permanently snow-covered, and only small areas on the top of the plateau near Mt. Kosciusko and in Tasmania are sufficiently elevated to be unable to support trees. These small areas of mountain grassland are omitted on the map.

METEOROLOGICAL SIGNIFICANCE

Variation in ground cover affects individual meteorological elements according to differences in thermal conductivity and specific heat. In regions covered with vegetation, incoming radiation is absorbed both by the vegetation and the surface of the earth. Where vegetation is lacking, i.e., in arid regions, the incoming radiation is absorbed by the surface only. Hence the incoming radiation is spread through a greater depth in the first case, while in the second it penetrates to a depth of only a few millimetres. Consequently, air overlying forested areas is not warmed to the same degree as air over more arid regions. In addition to this, differences in temperature between ground covered by vegetation and the air above are much smaller, owing to the higher albedo of the vegetation and to the use of incoming radiation for evaporation from the surface presented by vegetation. On the other hand, loss of heat by outgoing radiation is less from surfaces covered with vegetation than over arid regions. Consequently, the diurnal variation of temperature is less over forest areas than over more arid areas. In summer, the surface air temperatures and lapse rates in the overlying air will be lower over more thickly forested areas, while the period of maximum temperatures will be somewhat delayed. During the winter, the surface air temperatures and the lapse rates in the overlying air will be higher than over areas where the vegetative covering is sparse.

With regard to winds, a forested area presents a rougher surface to the free flow of the air, and so increases eddy motion and extends turbulence to higher levels. This will tend to establish an adiabatic lapse rate through the turbulent layer, at the same time mixing the atmosphere and extending upwards the water vapour absorbed into the air by evaporation of moisture from the relatively damp vegetative covering. This results in an increase in the relative and specific humidity upwards. Also forested areas present to relatively moist winds flowing over them a damper surface and a more humid overlying layer of air than do more arid areas. Hence these winds retain most of their moisture, and with turbulence carrying and distributing the water vapour upwards the result will be greater cloud amount, lower cloud heights, and higher rainfall. In fact, densely forested areas and jungles such as the tropical forests along the east coast will tend to resemble sources of maritime air masses.

SECTION 7—SUPPLEMENTARY NOTES

FLYING CONDITIONS ASSOCIATED WITH CLOUD

1. AEROPLANE CONDENSATION TRAILS

A feature of high altitude flying is the formation of "condensation trails" or "cloud trails" behind aircraft. The ordinary condensation trail starts as a short feathery plume a few yards behind the aircraft. It appears to form at first for only a few hundred yards in length and then to evaporate. As the aircraft gains altitude, and the temperature drops lower, the plume grows denser until quite suddenly it becomes a permanent trail, and often persists in the sky for many miles behind the aircraft. They are of considerable tactical importance since the cloud stream thus formed betrays the position of the aircraft and the track it is following.

The formation of these cloud trails is considered to be due to a number of contributing factors. **Firstly,** they may form because of the expansion and cooling of the air accompanying the reduction of pressure caused in eddies at the wing tips. If the air is saturated, or nearly so, the cooling may be sufficient to cause condensation. **Secondly,** the resulting turbulent motion of the air produced by the passage of the aircraft causes a disturbance of an unstable state, when, in the case of water clouds, the air is saturated with respect to water and has no nuclei, and, in the case of ice clouds, it is supersaturated with respect to ice, and has nuclei. **Thirdly,** the escape of exhaust gas into the air increases the supply of nuclei which may cause sublimation where the air is supersaturated with respect to ice. **Fourthly,** it is claimed by Humphreys that the addition of water to the air from the exhaust is ample for the formation of the trail cloud. In any case they are most likely to occur in a relatively moist layer of atmosphere, that is, in maritime air.

The actual height, at which the permanent trails form, appears to vary over large limits, and probably varies with the type of engine, the type of fuel, the type of exhaust manifold, and the relative humidity of the air. Persistent trails have been found to form frequently in the presence of cirriform or very high alto level clouds, although the presence of such clouds is not a necessary phenomenon. However, if a short trail commences to form, and if there are any traces of cloud in the vicinity, then there is every possibility of a permanent trail being made. Sometimes the layer of cloud in which the trail is made is quite thin and the trail ceases again higher up. This sometimes occurs when the trail is formed in a layer of cirrus and ceases again just above the layer. More usually, however, the permanent trail once started,

continues up to the tropopause and seems to cease at, or very shortly above it (about 1,500 feet above the tropopause). In the stratosphere, only short trails tend to form and they quickly evaporate. This points to the fact that the higher layers of the troposphere form a potentially dangerous region for the formation of permanent cloud trails. It must be remembered that the height of the tropopause varies from day to day, with the changing synoptic situation, being in general higher over an anticyclone and lower over a depression. Its height over the centre of an anticyclone may be 10,000 feet higher than over the centre of a depression. In addition to the daily variation in the height of the tropopause, there is a slow seasonal change in the mean height, it being a few thousand feet lower in winter than it is in summer. There is also a large change with latitude, the level of the tropopause lowering from the equator towards temperate latitudes by some 15,000 feet to 20,000 feet.

Persistent trails have been found to form most frequently in temperatures below — 40° C. (particularly from — 40° to — 48° C.). However, these trails may form in higher temperatures up to — 10° C., and, in fact, a persistent trail was seen over Sydney to form from 16,000 feet to 25,000 feet, when the temperature at 16,000 feet was — 15° C. However, the formation of trails at such relatively low altitudes is rare. At very low temperatures, or high altitudes, the saturation vapour pressure with respect to ice is very small, and, consequently, a much smaller fall of temperature is required to induce supersaturation than at higher temperatures. Hence the chance of trails forming increases with height; this is so particularly when the air has been lifted by some means (as in advance of a warm front or behind a cold front) or has been cooled by the expansion resulting from a fall of pressure.

From present knowledge it seems that the ranges of heights in which persistent trails are most likely to occur may be given as follows:—

Latitude	Summer	Winter.
0° S.	32,000 feet to 50,000 feet	32,000 feet to 55,000 feet
10° S.	35,000 feet to 55,000 feet	32,000 feet to 55,000 feet
20° S.	35,000 feet to 55,000 feet	30,000 feet to 50,000 feet
30° S.	30,000 feet to 50,000 feet	25,000 feet to 45,000 feet
40° S.	25,000 feet to 45,000 feet	20,000 feet to 38,000 feet

2. THE OPERATIONAL VALUE OF CLOUDS

Clouds may have operational values in different ways:—

(a) **Direct Value**

1. Aircraft may take refuge and evade a pursuing aeroplane by entering cloud and changing height when screened by the cloud. The correct use of cloud cover provides the bomber with a high degree of security against the enemy defences and fighters.

2. Aircraft may approach a target under cover of a cloud, and endeavour to come out of the cloud only when within striking distance.

3. Aircraft may approach a target in clear air above an extensive sheet of cloud, and so be concealed from below.

4. When the cloud is 10/10ths or nearly so, it is usually best for aircraft to operate individually, but when the cloud is more broken it may be better to retain section formation.

(b) **Indirect Value**

Certain types of clouds, such as Cs., As., etc., are often a good indication of the type of weather and cloud to be expected either in the near future or in different directions. A good knowledge of clouds will, therefore, be indirectly of value to pilots in planning their future movements.

In considering clouds for operational purposes, the following aspects must be borne in mind:—

(a) The degree of continuity of the cloud.
(b) The height of the base of the cloud.
(c) The depth or thickness of the cloud.
(d) The visibility within the cloud.
(e) The degree of bumpiness within the cloud.
(f) The risk of ice accretion within the cloud.

3. OPERATIONAL VALUE OF INDIVIDUAL CLOUD TYPES

Type	Operational Value		Significance
	Direct	Indirect	
1. Cirrus 2. Cirro-stratus	None. None.	May give warning of deteriorating weather. If cirrus wisps become more compact until they form cirro-stratus a warm front may be located 300 miles or more away.	Too high and thin for direct use. Indicate favourable conditions for formation of persistent trails. Icing does not vary in cirrus clouds.
3. Cirro-cumulus	None.	Generally of little value.	Too high and thin for direct use. Indicate favourable conditions for formation of persistent trails.

Type	Operational Value		Significance
	Direct	Indirect	
4. Alto-cumulus	Little value when, as is usual, it is broken into cloudlets. It will not afford complete screening to aircraft and the cloudlets are themselves too small to be of much value for evasion. It will, however, be frequently possible for pilots to make an alteration of course which will be unobserved by a hostile aircraft, thereby emerging from the cloud in an unexpected direction.	Generally of little value.	Generally too broken and lacking in continuity as it usually consists of small and isolated globular masses. Severe bumpiness in "castellatus" type. The banded type often indicates the approach of a front.
5. Alto-stratus	Good. It affords continuous cover and pilots will be free to make alterations of course which will be unobserved by hostile aircraft. In the thinner type visibility may be 1,000 yards, but when the cloud thickens the visibility will decrease rapidly and in thick alto-stratus may be as low as 20 to 100 yards.	Warning of deteriorating weather.	Visibility good. Suitable for formation flying. If alto - stratus thick, most suitable conditions in upper portions of cloud. Danger where sheet lowers to nimbo-stratus. Icing risk then great and visibility poor.
6. Strato-cumulus	Great, not only for continuous flight by a single aircraft but also for formation flying except when cumulus and cumulo - nimbus penetrate it. The cloud may have a vertical thickness of 500 to 3000 feet. Visibility about 10 to 30 yards.	Generally indicates good weather and good flying conditions above the cloud.	Suitable for formation flying by small aircraft, especially trained pilots, or for single aircraft cloud flying. May be used for flying in the cloud or above the cloud or both. Bumpiness experienced in penetrating inversion above cloud layer. If mixed with Cu or Cb clouds dangerous, as they are regions of turbulence and bad visibility. Icing may occur when the temperature is between 0° C. and — 7° C. but rate of accretion is not rapid.

Type	Operational Value		Significance
	Direct	Indirect	
7. Nimbo-stratus	Dangerous, particularly at low levels. Cloud may extend to surface. Vertical thickness may extend to 15,000 feet.	Bad weather.	Flight only practical for single aircraft. Unsuitable for formation flying. Bad visibility, less than 20 yards, and on many occasions less than 10 yards. Severe bumpiness. Its low base may envelop hills. Precipitation and dangerous icing risk.
8. Cumulus	Only useful for evasion.	Little value.	Lack of continuity, poor visibility (generally less than 20 yards), severe or violent bumpiness, violent vertical currents. Liable to heavy ice accretion when large (particularly between 0° C. and — 15° C.). Good opportunities for evasion when cloudy conditions.
.9 Cumulo-nimbus	Dangerous. Impossible for formation flying, unsuitable for single aircraft.	Little value.	Should be avoided. Violent bumpiness due to violent vertical currents. Visibility very bad, frequently less than 10 yards. Danger of heavy ice accretion between 0° and-20° C. Risk of damage from lightning (trailing aerials should be wound in). Damage from hail. Heavy precipitation.
10. Stratus	Only suitable over the sea. Usually too shallow and too low.	Good weather and flying conditions above the cloud.	Unsuitable for cloud flying because of low base; better out to sea.

4. THE TACTICAL USE OF CLOUDS

There are no hard and fast rules on the use which a pilot or a leader should make of cloud. The flying conditions associated with each individual type of cloud must be borne in mind.

It is possible for a squadron formation to fly in complete visual touch only when the visibility in cloud is comparatively good. This is possible in thin altostratus or at the upper portions of thick altostratus cloud. A section of aircraft can fly in visual forma-

tion at any rate for short periods, in comparatively opaque clouds. The advantage of visual flight formation is that when the formation runs out of cloud into clear air it is in a position to defend itself with the concentrated fire of all aircraft. However, aircraft are affected by loss of manœuvrability and speed and the danger of collision.

Cloud flying in formations larger than a section is normally impracticable. When a leader anticipates having to fly in cloud he orders other following sections to drop backwards and outwards in order to ensure sufficient spacing between sections so that each section may be able to break up into individual aircraft if necessary. Although a section may be flown in visual formation through certain types of cloud, two methods of breaking up the formation are employed if the cloud suddenly thickens, the visibility becomes too bad or misting of the perspex occurs. These are:—

(a) Wing aircraft turn outwards for a few minutes and then re-assume original course and speed.

(b) The leader flies straight and level, Nos. 2 and 3 aircraft pull upward to different levels and then resume their original course and speed. This break-up may be carried out in the open before entering the cloud or in cloud when the cloud has become too thick.

Further considerations applying to the tactical use of clouds, especially with regard to single aircraft, are:—

(a) When an aircraft is being pursued by an enemy aircraft and enters a cloud, the pilot should not fly straight through it but should turn while in the cloud in order to come out in an unexpected direction.

(b) The pilot should always be ready when in cloud to make a sharp turn for the next nearest cloud as soon as he enters the open.

(c) When flying in the level of a cloud layer 2/10ths of cloud ahead will look as if it were 10/10ths. If a pilot wishes to estimate the amount of cloud ahead, he should ascend about 2,000 feet.

(d) Scattered or well-broken cloud with small gaps is better for tactical purposes than the same amount with large gaps.

(e) The best use a pilot makes of a very thin layer of cloud when being pursued by an enemy aircraft is to pop up and down through it alternately, taking a steep turn whenever he emerges from cloud.

(f) Pilots must always beware of ice accretion.

(g) If an aircraft is being pursued by an enemy aircraft who is getting ready to attack and a cloud is two to three thousand feet away, the pilot should not dive straight for the cloud.

APPENDIX 1.

- STANDARD TIMES -

The tables given below relate certain standard times and Greenwich Mean Time.

Ahead of G.M.T.

H.M.	
0630	Burma, Cocos Islands, Northern Sumatra, Nicobar Islands.
0700	Bangka Island, Billiton Island, Christmas Island, French-Indo-China, Hainan Island, Siam, Southern Sumatra, Federated Malay States.
0730	Bali Island, Dutch Borneo, Lombok Island, Madura Island, Sarawak.
0800	British North Borneo, China Coast, Flores Island, Labuan Island, Philippine Islands, Sumbawa, Timor, Western Australia.
0830	Moluccas Islands.
0900	Aru Islands, Caroline Islands (west of 142°E), Japan, Jappen Islands, Kei Islands, Korea, Schouten Island, Tanimbar Island.
0930	Broken Hill Area, Northern Territory, South Australia.
1000	Admiralty Islands, Caroline Islands (from 142° E - 154°E), Ladrones Islands, Queensland, Willis Island New South Wales, Solomon Islands (west of 157½°E) Victoria, Tasmania, Lord Howe Island.
1100	Caroline Islands (east of 154°) Marshall Islands, New Caledonia, New Hebrides, Ocean Island, Naura Island, Solomon Islands (east of 157½°)
1130	Chatham Island, New Zealand, Norfolk Island.
1200	Fiji Islands, Gilbert & Ellice Islands.
1230	Friendly Islands, Tonga Islands.

G.M.T.	Eastern States Qld., N.S.W., VIC., Tas., L. Howe Is., Standard Time	 Summer Time	Central States S. Australia N. Territory Standard Time	 Summer Time	Western States W. Australia Standard Time	 Summer Time
0000	1000 am	1100 am	0930 am	1030 am	0800 am	0900 am
0030	1030	1130	1000	1100	0830	0930
0100	1100	noon	1030	1130	0900	1000
0130	1130	1230pm	1100	noon	0930	1030
0200	noon	0100	1130	1230 pm	1000	1100
0230	1230 pm	0130	noon	0100	1030	1130
0300	0100	0200	1230 pm	0130	1100	noon
0330	0130	0230	0100	0200	1130	1230 pm
0400	0200	0300	0130	0230	noon	0100
0430	0230	0330	0200	0300	1230 pm	0130
0500	0300	0400	0230	0330	0100	0200
0530	0330	0430	0300	0400	0130	0230
0600	0400	0500	0330	0430	0200	0300
0630	0430	0530	0400	0500	0230	0330
0700	0500	0600	0430	0530	0300	0400
0730	0530	0630	0500	0600	0330	0430
0800	0600	0700	0530	0630	0400	0500
0830	0630	0730	0600	0700	0430	0530
0900	0700	0800	0630	0730	0500	0600
0930	0730	0830	0700	0800	0530	0630
1000	0800	0900	0730	0830	0600	0700
1030	0830	0930	0800	0900	0630	0730
1100	0900	1000	0830	0930	0700	0800

1130	0930	1030	0900	1000	0730	0830
1200	1000	1100	0930	1030	0800	0900
1230	1030	1130	1000	1100	0830	0930
1300	1100	m'night	1030	1130	0900	1000
1330	1130	1230 am	1100	m'night	0930	1030
1400	m8night	0100	1130	1230 am	1000	1100
1430	1230 am	0130	m'night	0100	1030	1130
1500	0100	0200	1230 am	0130	1100	m'nigt
1530	0130	0230	0100	0200	1130	1230 am
1600	0200	0300	0130	0230	m'night	0100
1630	0230	0330	0200	0300	1230 am	0130
1700	0300	0400	0230	0330	0100	0200
1730	0330	0430	0300	0400	0130	0230
1800	0400	0500	0330	0430	0200	0300
1830	0430	0530	0400	0500	0230	0330
1900	0500	0600	0[illegible]30	0530	0300	0400
1930	0530	0630	0500	0600	0330	0430
2000	0600	0700	0530	0630	0400	0500
2030	0630	0730	0600	0700	0430	0530
2100	0700	0800	0630	0730	0500	0600
2130	0730	0830	0700	0800	0530	0630
2200	0800	0900	0730	0830	0600	0700
2230	0830	0930	0800	0900	0630	0730
2300	0900	1000	0830	0930	0700	0800
2330	0930	1030	0900	1000	0730	0830

[illegible] [illegible] [illegible] of [illegible]

— winds.

Clouds formed by
(1) Thermal Convection < [illegible] / Advection [illegible]
(2) Frontal uplift
(3) Topography
(4) Convergence
(5) Local Reduction of Pressure
— important for [illegible]

L.Cu	N.S	Sc & St
(1) C.E. Thermal Convection [illegible] [illegible] [illegible]	(1) W.F.	(1) Turbulence beneath [illegible] [illegible] — [illegible]
(2) Topog. uplift [illegible]	(2) S Occlusion	(2) Advection of warm air over cold surface
(3) cool from above [illegible] over sea	(3) C.F.	
W.F. [illegible] possible	(4) Convergence	
[illegible] [illegible]	$\boxed{5}$ Topograph uplift stable	